Dear Colleague,

Trying to cover all of biology in a single textbook is a terrifying, exhilarating, humbling, and sometimes overwhelming experience. But, if we had to pick a single word to describe our experience in writing this book, both of us would say “amazing.”

Why? Because the more we learn about biology, the more we are astonished at how much science has progressed since our student days, and how much more we have yet to learn about the natural world. We wrote this book because we want to share with you and your students our amazement at scientific progress, our awe at the wonder of nature, and our delight with the way science works.

It’s easy for students to get overwhelmed by the amount of information presented in an intro bio course. From molecules to the biosphere, there’s an awful lot of stuff to learn. All this “stuff” can give students the impression that biology “is done”—that everything has been figured out. Scientists, a student once told us, are ashamed to admit that there’s anything they don’t know.

That student was dead wrong, and we wrote this book to help you correct that kind of misunderstanding. Scientists aren’t interested in just memorizing what is known, but in using scientific methodology to explore what is not known. Beginning with Chapter 1, we’ve tried to present the “stuff” your students are required to know in a context that helps them share in the excitement that scientists feel as we investigate unsolved problems and unexplored territory in the living world.

If you find this book useful, we’ll be happy. As teachers, you are the most important part of the scientific community. You are the nurturers of new talent, the caretakers of youthful curiosity. You can help invigorate the scientific enterprise with hope, energy, and vigor. We hope you’ll share your thoughts, suggestions, and criticisms of this textbook with us, because we know we’ll learn from them. And, most especially, we thank you for the honor of sharing your classroom with us.

Ken Miller
Joe Levine
Chapter 1 • Flash Cards

The Science of Biology

Science as a Way of Knowing

Q: What role does science play in the study of life?

Have students read over the Chapter Mystery and discuss the use of human growth hormone (HGH) in individuals who are short but otherwise healthy. Then, ask students to explain how the Chapter Mystery illustrates the connection between science and society. Help them relate the discussion to the Chapter 1 Big Idea of Science as a Way of Knowing.

Have students preview the chapter vocabulary using the Flash Cards.

Connect to the Big Idea

Use the photograph of the paleontologists to start a class discussion of the methods scientists use to gather data. Ask students how these scientists are learning about this species of dinosaur. (Sample answer: They are observing the dinosaur’s skeleton.) Challenge students to describe other methods scientists use to learn about the natural world. (Students may identify methods such as experimentation or describe the use of technology to gather information.) Then, ask students to identify some of the topics that scientists study. Guide students to anticipate the answer to the question, What role does science play in the study of life?

Have students read over the Chapter Mystery and discuss the use of human growth hormone (HGH) in individuals who are short but otherwise healthy. Then, ask students to explain how the Chapter Mystery illustrates the connection between science and society. Help them relate the discussion to the Chapter 1 Big Idea of Science as a Way of Knowing.

Understanding by Design

Chapter 1 describes science, explains the relationship between science and society, and introduces the study of life. The graphic organizer at the right shows how these concepts are framed by the chapter Big Idea, Essential Question, and Guiding Questions. The idea and questions help students begin to explore the Unit 1 Enduring Understanding of how the process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

Performance Goals

In Chapter 1, students explore the process of science and the study of biology by reviewing detailed figures. They also preview the Big Ideas that run through biology and this textbook. They synthesize chapter concepts by writing a letter to Aristotle explaining how science has changed over time and an editorial encouraging all students to take a science course.

National Science Education Standards

Unifying Concepts and Processes

I, II, III, IV, V

Content

C.1.a, C.2.a, C.3.a, C.5.b, C.6.b, E.2, F.6, G.1, G.2, G.3

Inquiry

A.1.b, A.1.c, A.1.f, A.2.a, A.2.b, A.2.c, A.2.d, A.2.e, A.2.f
A doctor injects a chemical into the body of an eight-year-old boy named David. This healthy boy shows no signs of disease. The “condition” for which he is being treated is quite common—David is short for his age. The medication he is taking is human growth hormone, or HGH.

HGH, together with genes and diet, controls growth during childhood. People who produce little or no HGH are abnormally short and may have other related health problems. But David has normal HGH levels. He is short simply because his parents are both healthy, short people.

But if David isn’t sick, why does his doctor prescribe HGH? Where does medicinal HGH come from? Is it safe? What does this case say about science and society? As you read this chapter, look for clues about the nature of science, the role of technology in our modern world, and the relationship between science and society. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the growth hormone mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

These paleontologists—biologists who study ancient life—are working to reconstruct the skeleton of Carcharodontosaurus, a giant dinosaur that lived over 90 million years ago. By using scientific skills such as observation and inference, scientists can learn how ancient animals lived. The huge teeth of this dinosaur are sharp and serrated like a knife, suited for eating meat—a lot of it!
What Is Science?

**Key Questions**

- What are the goals of science?
- What procedures are at the core of scientific methodology?

**Vocabulary**
- science
- observation
- inference
- hypothesis
- controlled experiment
- independent variable
- dependent variable
- control group
- data

**Taking Notes**

**Flowchart**
As you read, create a flowchart showing the steps scientists use to answer questions about the natural world.

**What Science Is and Is Not**

**What are the goals of science?**

This book contains lots of facts and ideas about living things. Many of those facts are important, and you will be tested on them! But you shouldn't think that biology, or any science, is just a collection of never-changing facts. For one thing, you can be sure that some “facts” presented in this book will change soon—if they haven’t changed already. What’s more, science is not a collection of unchanging beliefs about the world. Scientific ideas are open to testing, discussion, and revision. So, some ideas presented in this book will also change.

These statements may puzzle you. If “facts” and ideas in science change, why should you bother learning them? And if science is neither a list of facts nor a collection of unchanging beliefs, what is it?

**FIGURE 1–1 Studying the Natural World**

How do whales communicate? How far do they travel? How are they affected by environmental changes? These are questions whale researchers can use science to answer.

**THINK ABOUT IT**

One day long ago, someone looked around and wondered: Where did plants and animals come from? How did I come to be? Since then, humans have tried to answer those questions in different ways. Some ways of explaining the world have stayed the same over time. Science, however, is always changing.

**What Science Is and Is Not**

**What are the goals of science?**

This book contains lots of facts and ideas about living things. Many of those facts are important, and you will be tested on them! But you shouldn't think that biology, or any science, is just a collection of never-changing facts. For one thing, you can be sure that some “facts” presented in this book will change soon—if they haven’t changed already. What’s more, science is not a collection of unchanging beliefs about the world. Scientific ideas are open to testing, discussion, and revision. So, some ideas presented in this book will also change.

These statements may puzzle you. If “facts” and ideas in science change, why should you bother learning them? And if science is neither a list of facts nor a collection of unchanging beliefs, what is it?
Science as a Way of Knowing  

Science is an organized way of gathering and analyzing evidence about the natural world. It is a way of observing, a way of thinking, and “a way of knowing” about the world. In other words, science is a process, not a “thing.” The word science also refers to the body of knowledge that scientific studies have gathered over the years.

Several features make science different from other human endeavors. First, science deals only with the natural world. Scientific endeavors never concern, in any way, supernatural phenomena of any kind. Second, scientists collect and organize information in an orderly way, looking for patterns and connections among events. Third, scientists propose explanations that are based on evidence, not belief. Then they test those explanations with more evidence.

The Goals of Science  
The scientific way of knowing includes the view that the physical universe is a system composed of parts and processes that interact. From a scientific perspective, all objects in the universe, and all interactions among those objects, are governed by universal natural laws. The same natural laws apply whether the objects or events are large or small.

Aristotle and other Greek philosophers were among the first to try to view the universe in this way. They aimed to explain the world around them in terms of events and processes they could observe. Modern scientists continue that tradition. ➤ One goal of science is to provide natural explanations for events in the natural world. Science also aims to use those explanations to understand patterns in nature and to make useful predictions about natural events.

Science, Change, and Uncertainty  
Over the centuries, scientists have gathered an enormous amount of information about the natural world. Scientific knowledge helps us cure diseases, place satellites in orbit, and send instantaneous electronic communications. Yet, despite all we know, much of nature remains a mystery. It is a mystery because science never stands still; almost every major scientific discovery raises more questions than it answers. Often, research yields surprises that point future studies in new and unexpected directions. This constant change doesn’t mean science has failed. On the contrary, it shows that science continues to advance.

That’s why learning about science means more than just understanding what we know. It also means understanding what we don’t know. You may be surprised to hear this, but science rarely “proves” anything in absolute terms. Scientists aim for the best understanding of the natural world that current methods can reveal. Uncertainty is part of the scientific process and part of what makes science exciting! Happily, as you’ll learn in later chapters, science has allowed us to build enough understanding to make useful predictions about the natural world.

In Your Notebook  
Explain in your own words why there is uncertainty in science.

How Science Works

THE SCIENCE OF BIOLOGY IN ANCIENT GREECE  

Although the word biology was not used until the early nineteenth century, the scientific study of life has a history of thousands of years. Alcmaeon, a Greek physician born about 535 b.c., is thought to be one of the first persons to have studied human anatomy. He discovered the optic nerve and speculated that the brain was the center of intellectual activity. The Greek philosopher Aristotle, born in 384 b.c., was a meticulous observer of living things, classifying over 500 animal species in a strict hierarchy. He even proposed a theory of progressive change among animals—a theory that anticipated the theory of evolution. 

Teach

Lead a Discussion  

Ask students the following questions to promote their understanding of what science is about.

Ask  How do you “know” about something?  
(Sample answer: You learn about something, or you see it for yourself.)

Ask  Where does knowledge come from? (Sample answer: From people who study particular topics.)

Ask  What does it mean to say that science is a process?  
(Sample answer: The word process indicates that science is something people do, rather than just a group of facts.)

Ask  Do you think the phrase “a way of knowing” accurately describes science as a method of learning? Why or why not?  
(Sample answer: Yes, the phrase identifies science as a method or tool used to learn about the natural world.)

DIFFERENTIATED INSTRUCTION

ELL Struggling Students  
Write the following sentence on the board:

• Science is an organized way of learning about the natural world.

Explain that this sentence summarizes the main idea presented on the page. Ask each student to give one detail about this main idea they learned by reading the page.

Focus on ELL: Extend Language

BEGINNING AND INTERMEDIATE SPEAKERS  Have students write the term science in a Vocabulary Word Map. Then, have them write words or phrases that describe attributes of science or topics related to science in the lower boxes. Encourage beginning speakers to use one of the boxes to make an illustration to represent the process of science. After students have completed their vocabulary word maps, have them form small groups to discuss how their maps are similar and how they are different. Circulate among the groups, and have students share some of their responses with you.


Answers

IN YOUR NOTEBOOK  
Sample answer: There is uncertainty in science because science rarely proves anything in absolute terms.
**Lesson 1.1 • Art in Motion • InterActive Art**

**Use Visuals**

Have students use Figure 1–3 to learn about scientific methodology. Point out to students that this figure continues through page 8. Have students make an outline that includes the following main topics: observing and asking questions, inferring and hypothesizing, designing controlled experiments, collecting and analyzing data, and drawing conclusions. As students read the detailed descriptions of these processes, have them add details to their outlines.

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** For students who are overwhelmed by the amount of information in Figure 1–3, have pairs of students go over each panel one by one. First, have individual students read the head, study the diagrams, and read through the captions below each set of panels. Then, suggest they discuss the panel with their partners. When they have discussed each panel, ask them to use their own words to tell the story presented by the entire series of panels.

**Address Misconceptions**

The *Scientific Method* A common misconception among students is that the “scientific method” is a set of five or six simple steps performed by all scientists, always in the same order. The text on this page can be used to address this misconception. Point out the sentences that refer to the dynamic nature of scientific investigations—how there is not any single, rigid set of steps called the scientific method. Tell students scientific methodology describes a general style of investigation and it applies across all the branches of science.

**Scientific Methodology: The Heart of Science**

What procedures are at the core of scientific methodology? You might think that science is a mysterious process, used only by certain people under special circumstances. But that’s not true, because you use scientific thinking all the time. Suppose your family’s car won’t start. What do you do? You use what you know about cars to come up with ideas to test. At first, you might think the battery is dead. So you test that idea by turning the key in the ignition. If the starter motor works but the engine doesn’t start, you reject the dead-battery idea. You might guess next that the car is out of gas. A glance at the fuel gauge tests that idea. Again and again, you apply scientific thinking until the problem is solved—or until you run out of ideas and call a mechanic!

Scientists approach research in pretty much the same way. There isn’t any single, cut-and-dried “scientific method.” There is, however, a general style of investigation that we can call scientific methodology.

Scientific methodology involves observing and asking questions, making inferences and forming hypotheses, conducting controlled experiments, collecting and analyzing data, and drawing conclusions. Figure 1–3 shows how one research team used scientific methodology in its study of New England salt marshes.

**Observing and Asking Questions** Scientific investigations begin with observation, the act of noticing and describing events or processes in a careful, orderly way. Of course, scientific observation involves more than just looking at things. A good scientist can, as the philosopher Arthur Schopenhauer put it, “Think something that nobody has thought yet, while looking at something that everybody sees.” That kind of observation leads to questions that no one has asked before.

**How Science Works**

**AN EMPHASIS ON EXPERIMENTATION**

Galileo Galilei (1564–1642) is generally considered to have established modern scientific methodology, as demonstrated in his investigations. Some stories about Galileo cannot be verified, but his approach to the study of nature is beyond question. His emphasis on experimentation as the way to prove the validity of ideas was part of the broader movement of free thought and skepticism that was characteristic of the European Renaissance. Galileo’s scientific legacy includes the challenge to Aristotle’s view that the natural state of a body is at rest—a view that had been accepted for 2000 years; and the discovery of Jupiter’s moons, which supported the Copernican model of the solar system.
Inferring and Forming a Hypothesis  After posing questions, scientists use further observations to make inferences. An inference is a logical interpretation based on what scientists already know. Inference, combined with a creative imagination, can lead to a hypothesis. A hypothesis is a scientific explanation for a set of observations that can be tested in ways that support or reject it.

Designing Controlled Experiments  Testing a scientific hypothesis often involves designing an experiment that keeps track of various factors that can change, or variables. Examples of variables include temperature, light, time, and availability of nutrients. Whenever possible, a hypothesis should be tested by an experiment in which only one variable is changed. All other variables should be kept unchanged, or controlled. This type of experiment is called a controlled experiment.

- Controlling Variables  Why is it important to control variables? The reason is that if several variables are changed in the experiment, researchers can’t easily tell which variable is responsible for any results they observe. The variable that is deliberately changed is called the independent variable (also called the manipulated variable). The variable that is observed and that changes in response to the independent variable is called the dependent variable (also called the responding variable).

- Control and Experimental Groups  Typically, an experiment is divided into control and experimental groups. A control group is exposed to the same conditions as the experimental group except for one independent variable. Scientists always try to reproduce or replicate their observations. Therefore, they set up several sets of control and experimental groups, rather than just a single pair.

In Your Notebook  What is the difference between an observation and an inference? List three examples of each.

Check for Understanding

HAND SIGNALS  Present students with the following questions, and ask them to show a thumbs-up sign if they can definitely answer the question, a thumbs-down sign if they cannot, or a waving-hand sign if they are not sure.

- Why is science sometimes referred to as a “way of knowing”?
- What are the goals of science?
- How is a controlled experiment designed?

ADJUST INSTRUCTION  If students are confused by a question, write it on the board and have small groups write a short response. Then, have volunteers from each group post their responses on the board.

Build Science Skills  Divide the class into small groups, and have each group consider this question: Does the amount of sleep a student gets affect how well that student does in school? Ask each group to design an experiment that would address the question. Have each group write a short summary of the procedure it would follow. Then, have groups share their experimental designs with the class.

DIFFERENTIATED INSTRUCTION

- Struggling Students  Help students understand the meaning of the terms independent variable and dependent variable in the context of a controlled experiment. Describe a simple experimental scenario to students, for example, giving several plants differing amounts of water to see how their growth is affected. Help students identify the independent variable and dependent variable in the experiment. Continue describing scenarios until they can reliably identify the independent and dependent variables. Then, have them apply this knowledge to the activity described above.

- Advanced Students  Ask students to use reliable resources to find out about studies of the amount of sleep teens receive and how their school performance is affected. Help students identify the independent variable and dependent variable in the experiment. Tell students to learn about the scientific methodology used in the studies. Have them share what they learn with the class.

Have students access Art in Motion: Experimental Design to manipulate the variables in the experiment in Figure 3–1. Students can also use the Interactive Art: Redi and Pasteur’s Experiments to explore the idea of spontaneous generation through experimentation.

Answers

IN YOUR NOTEBOOK  Students should explain that an observation, which is something noticed using the senses, is different from an inference, which is a logical interpretation of an observation. Students should list three examples of each.
Collecting and Analyzing Data

The researchers sampled all the plots throughout the growing season. They measured growth rates and plant sizes, and analyzed the chemical composition of living leaves.

Drawing Conclusions

Data from all plots were compared and evaluated by statistical tests. Data analysis confirmed that marsh grasses in experimental plots with additional nitrogen did, in fact, grow taller and larger than controls. The hypothesis and its predictions were supported.

How Science Works

THE USE OF STATISTICS IN SCIENCE

Data analysis in science often relies on the use of statistics. Although some statistical calculations are very sophisticated, calculations as basic as finding the mean, median, and mode of a set of values are ways to analyze data using statistics. Statistical tools such as range and standard deviation can be used to assess the variability of data. Statistics can also be used to calculate the percent error of experimental data. Percent error is calculated by obtaining the absolute value of the difference between the accepted value and the experimental value, dividing by the accepted value, and multiplying by 100.

\[
\text{% error} = \left| \frac{\text{experimental value} - \text{accepted value}}{\text{accepted value}} \right| \times 100
\]
Drawing Conclusions  Scientists use experimental data as evidence to support, refute, or revise the hypothesis being tested, and to draw a valid conclusion. Hypotheses are often not fully supported or refuted by one set of experiments. Rather, new data may indicate that the researchers have the right general idea but are wrong about a few particulars. In that case, the original hypothesis is reevaluated and revised; new predictions are made, and new experiments are designed. Those new experiments might suggest changes in the experimental treatment or better control of variables. As shown in Figure 1–4, many circuits around this loop are often necessary before a final hypothesis is supported and conclusions can be drawn.

When Experiments Are Not Possible  It is not always possible to test a hypothesis with an experiment. In some of these cases, researchers devise hypotheses that can be tested by observations. Animal behavior researchers, for example, might want to learn how animal groups interact in the wild. Investigating this kind of natural behavior requires field observations that disturb the animals as little as possible. When researchers analyze data from these observations, they may devise hypotheses that can be tested in different ways.

Sometimes, ethics prevents certain types of experiments—especially on human subjects. Medical researchers who suspect that a chemical causes cancer, for example, would not intentionally expose people to it! Instead, they search for volunteers who have already been exposed to the chemical. For controls, they study people who have not been exposed to the chemical. The researchers still try to control as many variables as possible. For example, they might exclude volunteers who have serious health problems or known genetic conditions. Medical researchers always try to study large groups of subjects so that individual genetic differences do not produce misleading results.

### 1.1 Assessment

#### Review Key Concepts

1. **a. Review** What is science?
   - **b. Explain** What kinds of understandings does science contribute about the natural world?
   - **c. Form an Opinion** Do you think that scientists will ever run out of things to study? Explain your reasoning.

2. **a. Review** What does scientific methodology involve?
   - **b. Explain** Why are hypotheses so important to controlled experiments?

#### Creative Writing

3. A few hundred years ago, observations seemed to indicate that some living things could just suddenly appear: maggots showed up on meat; mice were found on grain; and beetles turned up on cow dung. Those observations led to the incorrect idea of spontaneous generation—the notion that life could arise from nonliving matter. Write a paragraph for a history magazine evaluating the spontaneous generation hypothesis. Why did it seem logical at the time? What evidence was overlooked or ignored?

#### Assessment Answers

1a. Science is an organized way of gathering and analyzing evidence gathered about the natural world.

1b. Science provides explanations for events in the natural world, an understanding of patterns in nature, and predictions about natural events.

1c. Sample answer: I don’t think that scientists will ever run out of things to study because every discovery raises new questions. Also, as technology improves, there will be new ways to investigate things.

2a. Scientific methodology involves observing and asking questions, inferring and hypothesizing, designing controlled experiments, collecting and analyzing data, and drawing conclusions.

2b. Hypotheses are so important to controlled experiments because they are testable explanations for a set of observations.

3. Students’ paragraphs should explain that the idea of spontaneous generation seemed valid in light of people’s everyday observations. However, this idea was not tested using scientific methodology. Evidence that was overlooked or ignored might include the fact that adult flies were present in an area before the maggots “appeared” in that same area.
Getting Started

Objectives
1.2.1 Explain how scientific attitudes generate new ideas.
1.2.2 Describe the importance of peer review.
1.2.3 Explain what a scientific theory is.
1.2.4 Explain the relationship between science and society.

Student Resources
Study Workbooks A and B, 1.2 Worksheets
Spanish Study Workbook, 1.2 Worksheets

Build Background
Before class, write a message on the board using a random arrangement of letters rather than recognizable words. When students ask you about the message, point out that they are demonstrating curiosity, one of the scientific habits of mind.

Science in Context

THINK ABOUT IT
Scientific methodology is the heart of science. But that vital “heart” is only part of the full “body” of science. Science and scientists operate in the context of the scientific community and society at large.

Exploration and Discovery: Where Ideas Come From

What scientific attitudes help generate new ideas?
Scientific methodology is closely linked to exploration and discovery, as shown in Figure 1–5. Recall that scientific methodology starts with observations and questions. But where do those observations and questions come from in the first place? They may be inspired by scientific attitudes, practical problems, and new technology.

Scientific Attitudes
Good scientists share scientific attitudes, or habits of mind, that lead them to exploration and discovery.

Curiosity
A curious researcher, for example, may look at a salt marsh and immediately ask, “What’s that plant? Why is it growing here?” Often, results from previous studies also spark curiosity and lead to new questions.

Skepticism
Good scientists are skeptics, which means that they question existing ideas and hypotheses, and they refuse to accept explanations without evidence. Scientists who disagree with hypotheses design experiments to test them. Supporters of hypotheses also undertake rigorous testing of their ideas to confirm them and to address any valid questions raised.

Open-Mindedness
Scientists must remain open-minded, meaning that they are willing to accept different ideas that may not agree with their hypothesis.

Creativity
Researchers also need to think creatively to design experiments that yield accurate data.

ENDURING UNDERSTANDING
The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

GUIDING QUESTION
How do the scientific community and society influence the process of science?

EVIDENCE OF UNDERSTANDING
After completing the lesson, give students the following assessment to show their understanding of scientific attitudes. Have students work with a small group to write and perform a skit that demonstrates how a scientist would employ each of the scientific habits of mind discussed (curiosity, skepticism, open-mindedness, and creativity) when exploring a scientific problem. Have each group perform its skit for the class.

UNIFYING CONCEPTS AND PROCESSES

CONTENT
E.2, F.6, G.1, G.2, G.3

INQUIRY
A.1.b, A.2.b, A.2.c, A.2.e, A.2.f

Teach for Understanding
How Science Works

APPLYING SCIENCE TO PRACTICAL PROBLEMS

The Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) are examples of government agencies that apply science to practical problems. The EPA helps develop and enforce regulations that protect the environment. The results of scientific studies, carried out either in EPA laboratories or by other researchers, are used when regulations are developed. The FDA applies science to help maintain public health. This agency is responsible for the safety of cosmetics, medical devices, and several other categories of products. Both the EPA and FDA also provide scientifically accurate information to the public for individuals to use as they make decisions about the environment and various products.

Practical Problems Sometimes, ideas for scientific investigations arise from practical problems. Salt marshes, for example, play vital roles in the lives of many ecologically and commercially important organisms, as you will learn in the next unit. Yet they are under intense pressure from industrial and housing development. Should marshes be protected from development? If new houses or farms are located near salt marshes, can they be designed to protect the marshes? These practical questions and issues inspire scientific questions, hypotheses, and experiments.

The Role of Technology Technology, science, and society are closely linked. Discoveries in one field of science may lead to new technologies. Those technologies, in turn, enable scientists in other fields to ask new questions or to gather data in new ways. For example, the development of new portable, remote data-collecting equipment enables field researchers to monitor environmental conditions around the clock, in several locations at once. This capability allows researchers to pose and test new hypotheses. Technological advances can also have big impacts on daily life. In the field of genetics and biotechnology, for instance, it is now possible to mass-produce complex substances—such as vitamins, antibiotics, and hormones—that were once available only naturally.

In Your Notebook Describe a situation where you were skeptical of a "fact" you had seen or heard.

FIGURE 1–6 Exploration and Discovery Ideas in science can arise in many ways—from simple curiosity or from the need to solve a particular problem. Scientists often begin investigations by making observations, asking questions, talking with colleagues, and reading about previous experiments.

FIGURE 1–7 Ideas From Practical Problems People living on a strip of land like this one in Murrells Inlet, South Carolina, may face flooding and other problems. Pose Questions: What are some scientific questions that can arise from a situation like this one?

Teach

Connect to Social Studies

Have students work in groups to identify a practical problem in their community, such as pollution, to which scientific investigation could be applied. Have students prepare a report describing the problem, how scientific attitudes could be used to learn more about it, and at least one way technology could be applied to solving it. Have each group share its report with the class.

DIFFERENTIATED INSTRUCTION

<table>
<thead>
<tr>
<th>Level</th>
<th>Advanced Students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Have students research actual examples of how science has been applied to a practical problem in their community or state. Have each student prepare a poster or slideshow with presentation software to share the findings.</td>
</tr>
</tbody>
</table>

Focus on ELL: Access Content

INTERMEDIATE AND ADVANCED SPEAKERS Have students create a Two-Column Table as they work through the lesson. Have them write down any new concepts they learn in the first column. In the second column, have them label each concept with a “+” if they understand it fully, or a “?” if they are confused about it. At the end of the lesson, suggest students work in pairs to discuss any concepts labeled with a question mark.

Study Wkbks A/B, Appendix S31, Two-Column Table. Transparencies, GO16.

Answers

FIGURE 1–7 Sample answer: Can vegetation be used to control flooding on the inlet?

IN YOUR NOTEBOOK Students’ notebook entries should identify questionable facts they have encountered, such as unrealistic product claims.
Use Visuals

Have students use Figure 1–8 to learn more about the role of communication in science.

Ask Why is the term “new ideas” found in the center of the diagram in Figure 1–8? (Each of the four processes in the corners of the diagram can lead to new ideas in science.)

Ask When a scientific paper is published, does that mean research about that topic is complete? Why or why not? (Sample answer: Publication of a paper does not mean that research about a topic is complete; it may open doors for many new studies about the same topic.)

DIFERENTIATED INSTRUCTION

Struggling Students Use the following sentence prompts to help students understand the information in Figure 1–8.

- Peer review can lead to new ideas by . . .
- Replication of results can lead to new ideas by . . .
- Discussion with colleagues can lead to new ideas by . . .
- Publication can lead to new ideas by . . .

Have students complete the sentences verbally or in written form. Discuss the completed sentences with students to be sure they understand how each process contributes to the formation of new ideas in science.

Answers

FIGURE 1–9 Sample answer: I would set up a controlled experiment in which extra nitrogen was supplied to a group of mangrove seedlings. I would then compare the growth of these seedlings over time to the growth of mangrove seedlings grown using the same concentration of nitrogen as in the salt marsh.

IN YOUR NOTEBOOK An article published without undergoing peer review might contain oversights or mistakes in techniques or reasoning. The research could also be fraudulent or biased.

Communicating Results: Reviewing and Sharing Ideas

Why is peer review important?

Data collection and analysis can be a long process. Scientists may focus intensely on a single study for months or even years. Then, the exciting time comes when researchers communicate their experiments and observations to the scientific community. Communication and sharing of ideas are vital to modern science.

Peer Review Scientists share their findings with the scientific community by publishing articles that have undergone peer review. In peer review, scientific papers are reviewed by anonymous, independent experts. Publishing peer-reviewed articles in scientific journals allows researchers to share ideas and to test and evaluate each other’s work. Scientific articles are like high-powered versions of your high school lab reports. They contain details about experimental conditions, controls, data, analysis, and conclusions. Reviewers read them looking for oversights, unfair influences, fraud, or mistakes in techniques or reasoning. They provide expert assessment of the work to ensure that the highest standards of quality are met. Peer review does not guarantee that a piece of work is correct, but it does certify that the work meets standards set by the scientific community.

Sharing Knowledge and New Ideas Once research has been published, it enters the dynamic marketplace of scientific ideas, as shown in Figure 1–8. How do new findings fit into existing scientific understanding? Perhaps they spark new questions. For example, the finding that growth of salt marsh grasses is limited by available nitrogen suggests other hypotheses: Is the growth of other plants in the same habitat also limited by nitrogen? What about the growth of different plants in similar environments, such as the mangrove swamp shown in Figure 1–9? Each of these logical and important questions leads to new hypotheses that must be independently confirmed by controlled experiments.

In Your Notebook Predict what might happen if an article is published without undergoing peer review.

CHECK FOR UNDERSTANDING

ONE-MINUTE RESPONSE

Give students about a minute to write a quick response to the following:

- Why is peer review an important part of communicating scientific results?

ADJUST INSTRUCTION

If students do not understand the importance of peer review, discuss the consequences of inaccurate or fraudulent scientific papers being published. Then, have them write a sentence that summarizes the impact this would have on the advancement of science.
Scientific Theories

**What is a scientific theory?**

Evidence from many scientific studies may support several related hypotheses in a way that inspires researchers to propose a scientific **theory** that ties those hypotheses together. As you read this book, you will often come across terms that will be new to you because they are used only in science. But the word **theory** is used both in science and in everyday life. It is important to understand that the meaning you give the word **theory** in daily life is very different from its meaning in science. When you say, “I have a theory;” you may mean, “I have a hunch.” When a friend says, “That’s just a theory” she may mean, “People aren’t too certain about that idea.” In those same situations, a scientist would probably use the word **hypothesis.** But when scientists talk about gravitational theory or evolutionary theory, they mean something very different from **hunch or hypothesis.**

**In science, the word theory applies to a well-tested explanation that unifies a broad range of observations and hypotheses and that enables scientists to make accurate predictions about new situations.** Charles Darwin’s early observations and hypotheses about change over time in nature, for example, grew and expanded for years before he collected them into a theory of evolution by natural selection. Today, evolutionary theory is the central organizing principle of all biological and biomedical science. It makes such a wide range of predictions about organisms—from bacteria to whales to humans—that it is mentioned throughout this book.

A useful theory that has been thoroughly tested and supported by many lines of evidence may become the **dominant** view among the majority of scientists, but no theory is considered absolute truth. Science is always changing; as new evidence is uncovered, a theory may be revised or replaced by a more useful explanation.

**Analyze and Conclude**

1. **Evaluate** How could you have written better directions?
2. **Infer** Why is it important that scientists write procedures that can be replicated?
Teach continued

Connect to the Real World
Use several of the topics relating to social issues raised in the first paragraph to start a discussion of the role science plays in personal/public health and environmental issues.

Ask How does science influence society? (Sample answer: Scientific data helps provide answers to questions that affect everyday lives.) Help students understand that scientists do not work in a vacuum. Instead, their research is strongly influenced by society.

Ask How does society influence science? (Sample answer: Society can limit the application of scientific ideas, especially if new scientific ideas conflict with prevailing cultural beliefs.)

DIFFERENTIATED INSTRUCTION
L3 Advanced Students Have students research a historical example of how scientific advancement was impeded by the society in which a scientist lived. For example, students might research Galileo, Copernicus, Wegener, or Darwin to find out how the acceptance of ideas was influenced by prevailing social beliefs and attitudes. Ask students to discuss their research and describe how—or if—this same situation applies today.

Science and Society

What is the relationship between science and society?
Make a list of health-related things that you need to understand to protect your life and the lives of others close to you. Your list may include drugs and alcohol, smoking and lung disease, AIDS, cancer, and heart disease. Other topics focus on social issues and the environment. How much of the information in your genes should be kept private? Should communities produce electricity using fossil fuels, nuclear power, solar power, wind power, or hydroelectric dams? How should chemical wastes be disposed of?

All these questions require scientific information to answer, and many have inspired important research. But none of these questions can be answered by science alone. These questions involve the society in which we live, our economy, and our laws and moral principles.

Using science involves understanding its context in society and its limitations. Figure 1–10 shows the role science plays in society.

Science, Ethics, and Morality When scientists explain “why” something happens, their explanation involves only natural phenomena. Pure science does not include ethical or moral viewpoints. For example, biologists try to explain in scientific terms what life is, how life operates, and how life has changed over time. But science cannot answer questions about why life exists or what the meaning of life is. Similarly, science can tell us how technology and scientific knowledge can be applied but not whether it should be applied in particular ways. Remember these limitations when you study and evaluate science.

Avoiding Bias The way that science is applied in society can be affected by bias. A bias is a particular preference or point of view that is personal, rather than scientific. Examples of biases include personal taste, preferences for someone or something, and societal standards of beauty.

Science aims to be objective, but scientists are human, too. They have likes, dislikes, and occasional biases. So, it shouldn’t surprise you to discover that scientific data can be misinterpreted or misapplied by scientists who want to prove a particular point. Recommendations made by scientists with personal biases may or may not be in the public interest. But if enough of us understand science, we can help make certain that science is applied in ways that benefit humanity.

Check for Understanding

ORAL QUESTIONING
Use the following prompts to gauge students’ understanding of lesson concepts.
• How are science and society related?
• Give an example of an ethical or moral question that science cannot address.
• What might happen if a scientist were biased?

ADJUST INSTRUCTION
A class discussion of students’ responses can be used to address concepts about which students have questions.

Answers

FIGURE 1–10 Sample answer: Yes, I think shellfish should be routinely screened for toxins because shellfish are an important source of food for many people. Without routine screening to check for toxins, many people could get sick or even die.
Science is considered a way of knowing. It helps you assess the validity of the ideas. Discuss why knowing the limitations of science is also important. (Sample answer: It is important to know what questions science cannot answer.)

DIFFERENTIATED INSTRUCTION

Special Needs Have students make a collage entitled How People Use Science. Help them find pictures that show how science impacts their own life.

Assess and Remediate

Evaluate Understanding

Have each student choose a main topic from the lesson and prepare a brief summary of it. Call on students to share their summaries with the class. Then, have them complete the 1.2 Assessment.

Remediation Suggestion

Struggling Students If students are struggling with Question 1b, have them review their answer to the In Your Notebook question on page 11.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. curiosity, skepticism, open-mindedness, creativity

1b. He or she questions existing ideas and hypotheses. Skepticism is important because scientists should refuse to accept explanations without evidence.

2a. the process by which scientific papers are reviewed by anonymous, independent experts

2b. There is no guarantee that the studies meet scientific standards.

3a. a well-tested explanation that unifies observations and hypotheses and enables scientists to make accurate predictions

3b. In science, theory means a well-tested explanation. In everyday usage, theory means an idea or a hunch.

4a. Sample answer: Science must take societal issues into account. Many questions cannot be answered by science alone and need input from society.

4b. Sample answer: Science does not include ethical or moral viewpoints. It may also be influenced by bias.

4c. Sample answer: The scientist might be biased by ties to the pesticide company.

5. Science is considered a way of knowing because it is not just a list of facts. It is a way of applying scientific methodology and attitudes to observations of the world.
CHAPTER FEATURE

Lead a Discussion
After students have read the feature, discuss their opinions about the funding of product safety studies.

Ask What is an advantage of having independent organizations fund product safety studies? (Sample answer: Independent organizations are less likely to be biased about a product’s safety.)

Ask What is an advantage of having private industry fund product safety studies? (Sample answer: Companies would do a better job testing their products than an independent agency, because their company’s reputation is at stake.)

Ask How does knowledge of scientific attitudes and methodology affect the way you evaluate product safety information? (Sample answer: Scientific attitudes, especially open-mindedness and skepticism, are vital when evaluating information about product safety. Knowledge of scientific methodology allows me to evaluate the studies performed on products.)

Answers

RESEARCH AND DECIDE

1. Answers will vary. Students’ responses should indicate that they have used reliable resources to learn about and compare studies related to BPA, cigarette smoke, and Teflon.

2. Answers will vary. Students’ responses should offer well-reasoned support for their opinion and a specific plan for dealing with bias when interpreting results.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP II

CONTENT F.6, G.1, G.2

INQUIRY A.1.f, A.2.b

Who Should Fund Product Safety Studies?

Biology plays a major role in the research, development, and production of food, medicine, and other consumer items. Companies that make these items profit by selling reliable and useful products in the marketplace. For example, the plastics industry provides countless products for everyday use.

But sometimes questions arise concerning product safety. Bisphenol-A (BPA), for instance, is a chemical found in hard plastics. Those plastics are used to make baby bottles, reusable water bottles, and the linings of many food and soft drink cans. Is BPA safe? This type of question can be posed as a scientific hypothesis to be tested. But who does the testing? Who funds the studies and analyzes the results?

Ideally, independent scientists test products for safety and usefulness. That way, the people who gather and analyze data can remain objective—they have nothing to gain by exaggerating the positive effects of products and nothing to lose by stating any risks. However, scientists are often hired by private companies to develop or test their products.

Often, test results are clear: A product is safe or it isn’t. Based on these results, the Food and Drug Administration (FDA) or another government agency makes recommendations to protect and promote public health. Sometimes, though, results are tough to interpret.

More than 100 studies have been done on BPA—some funded by the government, some funded by the plastics industry. Most of the independent studies found that low doses of BPA could have negative health effects on laboratory animals. A few studies, mostly funded by the plastics industry, concluded that BPA is safe. In this case, the FDA ultimately declared BPA to be safe. When the issue of BPA safety hit the mass media, government investigations began. So, who should sponsor product safety studies?

The Viewpoints

Independent Organizations Should Fund Safety Studies

Scientists performing safety studies should have no affiliation with private industries, because conflict of interest seems unavoidable. A company, such as a BPA manufacturer, would naturally benefit if its product is declared to be safe. Rather, safety tests should be funded by independent organizations such as universities and government agencies, which should be as independent as possible. This way, recommendations for public health can remain free of biases.

Private Industries Should Fund Safety Studies

There are an awful lot of products out there! Who would pay scientists to test all those products? There are simply too many potentially useful and valuable products being developed by private industry for the government to keep track of and test adequately with public funds. It is in a company’s best interest to produce safe products, so it would be inclined to maintain high standards and perform rigorous tests.

Research and Decide

1. Analyze the Viewpoints To make an informed decision, research the current status of the controversy over BPA by using the Internet and other resources. Compare this situation with the history of safety studies on cigarette smoke and the chemical Teflon.

2. Form an Opinion Should private industries be able to pay scientists to perform their product safety studies? How would you deal with the issue of potential bias in interpreting results?

Quick Facts

WHAT IS THE U.S. CONSUMER PRODUCT SAFETY COMMISSION?
The U.S. Consumer Product Safety Commission is an agency of the U.S. government that deals with the safety of many products that people use every day. It is an independent agency within the government. Its responsibilities include helping develop voluntary standards that can be followed by manufacturers, collecting information about injuries and other harm caused by consumer products, researching potentially hazardous products, and issuing recalls for products that are hazardous. Individuals who have been harmed by a consumer product can contact the U.S. Consumer Product Safety Commission to report the incident. The agency’s Web site offers updated information about product recalls and safety issues.
Studying Life

THINK ABOUT IT Think about important and exciting news stories you’ve seen or heard. Bird flu spreads around the world, killing thousands of birds and threatening a human epidemic. Users of certain illegal drugs experience permanent damage to their brains and other parts of their nervous systems. Reports surface about efforts to clone human cells to grow new organs to replace those lost to disease or injury. These and many other stories involve biology—the science that employs scientific methodology to study living things. (The Greek word bios means “life,” and -logy means “study of.”)

Characteristics of Living Things
What characteristics do all living things share?

Biology is the study of life. But what is life? What distinguishes living things from nonliving matter? Surprisingly, it isn’t as simple as you might think to describe what makes something alive. No single characteristic is enough to describe a living thing. Also, some nonliving things share one or more traits with organisms. For example, a firefly and fire both give off light, and each moves in its own way. Mechanical toys, automobiles, and clouds (which are not alive) move around, while mushrooms and trees (which are alive) stay in one spot. To make matters more complicated, some things, such as viruses, exist at the border between organisms and nonliving things.

Despite these difficulties, we can list characteristics that most living things have in common. Living things are made up of basic units called cells, are based on a universal genetic code, obtain and use materials and energy, grow and develop, reproduce, respond to their environment, maintain a stable internal environment, and change over time.

FIGURE 1–12 Is It Alive? The fish are clearly alive, but what about the colorful structure above them? Is it alive? As a matter of fact, it is. The antlerlike structure is actually a marine animal called elk horn coral. Corals show all the characteristics common to living things.

Key Questions
What characteristics do all living things share?
What are the central themes of biology?
How do different fields of biology differ in their approach to studying life?
How is the metric system important in science?

Vocabulary
biology • DNA • stimulus • sexual reproduction • asexual reproduction • homeostasis • metabolism • biosphere

Taking Notes
Concept Map As you read, draw a concept map showing the big ideas in biology.

Teach for Understanding

ENDURING UNDERSTANDING The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

GUIDING QUESTION What is biology?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show their understanding of the study of life. Have students work with a partner to identify a problem or question related to life science. Then, ask students to compare and contrast how scientists from two different fields of biology would approach this problem. Have each pair write a paragraph summarizing their discussion.
The Characteristics of Living Things

FIGURE 1–13  Apple trees share certain characteristics with other living things. Compare and Contrast: How are the apple tree and the grass growing below similar? How are they different?

Living things are based on a universal genetic code. All organisms store the complex information they need to live, grow, and reproduce in a genetic code written in a molecule called DNA. That information is copied and passed from parent to offspring. With a few minor variations, life's genetic code is almost identical in every organism on Earth.

Living things grow and develop. Every organism has a particular pattern of growth and development. During development, a single fertilized egg divides again and again. As these cells divide, they differentiate, which means they begin to look different from one another and to perform different functions.

Living things respond to their environment. Organisms detect and respond to stimuli from their environment. A stimulus is a signal to which an organism responds.

Some plants can produce unsavory chemicals to ward off caterpillars that feed on their leaves.

Answers

FIGURE 1–13 Sample answer: The apple tree and the grass are similar in that both contain DNA, are made of cells, reproduce, grow and develop, use materials and energy, respond to their environment, and maintain a stable environment; they differ in that an apple tree contains many more cells than an individual grass plant.

How Science Works

A CONSTANT "INTERNAL MILIEU"

In 1851, French physiologist Claude Bernard discovered that nerves in an animal's body control the dilation and constriction of blood vessels. He observed that on hot days the blood vessels of the skin become dilated, whereas on cold days those same blood vessels become constricted. Bernard explained that these changes functioned to regulate body temperature. He concluded that, even when the external environment changes, an animal has a way of maintaining a constant "internal milieu." His concept of the maintenance of an internal balance within an organism is incorporated in the modern concept of homeostasis, which literally means "same condition."
Living things reproduce. All organisms reproduce, which means that they produce new similar organisms. Most plants and animals engage in sexual reproduction. In sexual reproduction, cells from two parents unite to form the first cell of a new organism. Other organisms reproduce through asexual reproduction, in which a single organism produces offspring identical to itself. 

- Beautiful blossoms are part of the apple tree’s cycle of sexual reproduction.

Living things maintain a stable internal environment. All organisms need to keep their internal environment relatively stable, even when external conditions change dramatically. This condition is called homeostasis.

- These specialized cells help leaves regulate gases that enter and leave the plant. SEM 1200X.

Living things obtain and use material and energy. All organisms must take in materials and energy to grow, develop, and reproduce. The combination of chemical reactions through which an organism builds up or breaks down materials is called metabolism.

- Various metabolic reactions occur in leaves.

Living things are made up of cells. Organisms are composed of one or more cells—the smallest units considered fully alive. Cells can grow, respond to their surroundings, and reproduce. Despite their small size, cells are complex and highly organized.

- A single branch of an apple tree contains millions of cells. LM 800X.

Taken as a group, living things evolve. Over generations, groups of organisms evolve, or change over time. Evolutionary change links all forms of life to a common origin more than 3.5 billion years ago. Evidence of this shared history is found in all aspects of living and fossil organisms, from physical features to structures of proteins to sequences of information in DNA.

- Signs of one of the first land plants, Cooksonia, are preserved in rock over 400 million years old.

Expand Vocabulary
Point out that the paragraphs describing the characteristics of living things in Figure 1–13 contain the majority of this lesson’s vocabulary terms. Have students work with a partner to make a flash card for each vocabulary term found on these two pages. Then, have students use the flash cards to review the definitions of the terms with their partner.

DIFFERENTIATED INSTRUCTION

ELL English Language Learners Pair students learning English with native English speakers for the activity described above. Encourage these pairs to focus on proper pronunciation of the terms in addition to their definitions. Circulate among pairs, and ask English language learners to share words and definitions with you.

ELL Advanced Students Those students who can easily learn the definitions of the vocabulary terms on these pages should be encouraged to use the index of this book to find out what chapters will further explore each of the vocabulary terms. For example, if a student looks up the term DNA in the index, he or she will note that DNA will be further discussed in chapters relating to the chemistry of life, genetics, biotechnology, and classification. Ask students to anticipate some of the topics related to each vocabulary term that they will learn about as they read the book.

allspeakers Have students use the information in Figure 1–13 to develop a class bulletin board on the characteristics of living things. Suggest that beginning and intermediate speakers draw or find visuals that represent each of the eight characteristics. Have these students work with advanced and advanced high speakers to write captions for each visual. The caption should explain how the visual showcases a particular characteristic of life. Ask advanced high students to write short summaries of each characteristic to help organize the bulletin board.

ALL SPEAKERS Have students use the information in Figure 1–13 to develop a class bulletin board on the characteristics of living things. Suggest that beginning and intermediate speakers draw or find visuals that represent each of the eight characteristics. Have these students work with advanced and advanced high speakers to write captions for each visual. The caption should explain how the visual showcases a particular characteristic of life. Ask advanced high students to write short summaries of each characteristic to help organize the bulletin board.

Check for Understanding

USE VOCABULARY
Have students make a crossword puzzle that includes each of the lesson vocabulary terms included in Figure 1–13. The clues for each term should be scientifically accurate and based on the definitions given in the text.

ADJUST INSTRUCTION
Collect the crossword puzzles and redistribute them at random. Ask students to complete the crossword puzzle they have been given. Then, have students return the crossword puzzle to the student who made it and talk about any clues they had difficulty matching a term with.
Big Ideas in Biology

What are the central themes of biology?

The units of this book seem to cover different subjects. But we’ll let you in on a secret: That’s not how biology works. All biological sciences are tied together by themes and methods of study that cut across disciplines. These “big ideas” overlap and interlock, and crop up again and again throughout the book. You’ll also notice that several of these big ideas overlap with the characteristics of life or the nature of science.

The study of biology revolves around several interlocking big ideas: The cellular basis of life; information and heredity; matter and energy; growth, development, and reproduction; homeostasis; evolution; structure and function; unity and diversity of life; interdependence in nature; and science as a way of knowing.

Big idea Cellular Basis of Life Living things are made of cells. Many living things consist of only a single cell; they are called unicellular organisms. Plants and animals are multicellular. Cells in multicellular organisms display many different sizes, shapes, and functions. The human body contains 200 or more different cell types.

Big idea Information and Heredity Living things are based on a universal genetic code. The information coded in DNA forms an unbroken chain that stretches back roughly 3.5 billion years. Yet, the DNA inside your cells right now can influence your future—your risk of getting cancer, the amount of cholesterol in your blood, and the color of your children’s hair.

Big idea Matter and Energy Living things obtain and use material and energy. Life requires matter that serves as nutrients to build body structures, and energy that fuels life’s processes. Some organisms, such as plants, obtain energy from sunlight and take up nutrients from air, water, and soil. Other organisms, including most animals, eat plants or other animals to obtain both nutrients and energy. The need for matter and energy link all living things on Earth in a web of interdependent relationships.

Big idea Growth, Development, and Reproduction All living things reproduce. Newly produced individuals are virtually always smaller than adults, so they grow and develop as they mature. During growth and development, generalized cells typically become more and more different and specialized for particular functions. Specialized cells build tissues, such as brains, muscles, and digestive organs, that serve various functions.

Big idea Homeostasis Living things maintain a relatively stable internal environment, a process known as homeostasis. For most organisms, any breakdown of homeostasis may have serious or even fatal consequences.

In Your Notebook Describe what happens at the cellular level as a baby grows and develops.

Analyze and Conclude

1. Interpret Graphs Which plant parts do siamangs rely on most as a source of their matter and energy?

2. Predict How would siamangs be affected if the rainforests they live in were cut down?

What’s in a Diet?
The circle graph shows the diet of the siamang gibbon, a type of ape found in the rainforests of Southeast Asia.

Leaves: 50%
Fruits: 40%
Flowers, buds, and insects: 10%

In Your Notebook Sample answer: As a baby grows and develops, generalized cells become more different and specialized for particular functions.

ANSWERS

1. leaves

2. Sample answer: Siamang gibbons are dependent on the trees in the rainforest, because most of their diet is made up of plant material. Therefore, these animals would not be able to get the food they need if the rainforest were cut down.
Evolution

Evolutionary change links all forms of life to a common origin more than 3.5 billion years ago. Evidence of this shared history is found in all aspects of living and fossil organisms, from physical features to structures of proteins to sequences of information in DNA. Evolutionary theory is the central organizing principle of all biological and biomedical sciences.

Structure and Function

Each major group of organisms has evolved its own particular body part “tool kit,”—a collection of structures that have evolved in ways that make particular functions possible. From capturing food to digesting it, and from reproducing to breathing, organisms use structures that have evolved into different forms as species have adapted to life in different environments. The structures of wings, for example, enable birds and insects to fly. The structures of legs enable horses to gallop and kangaroos to hop.

Unity and Diversity of Life

Although life takes an almost unbelievable variety of forms, all living things are fundamentally similar at the molecular level. All organisms are composed of a common set of carbon-based molecules, store information in a common genetic code, and use proteins to build their structures and carry out their functions. One great contribution of evolutionary theory is that it explains both this unity of life and its diversity.

Interdependence in Nature

All forms of life on Earth are connected into a biosphere, which literally means “living planet.” Within the biosphere, organisms are linked to one another and to the land, water, and air around them. Relationships between organisms and their environments depend on the cycling of matter and the flow of energy. Human life and the economies of human societies also require matter and energy, so human life depends directly on nature.

Science as a Way of Knowing

Science is not a list of facts, but “a way of knowing.” The job of science is to use observations, questions, and experiments to explain the natural world in terms of natural forces and events. Successful scientific research reveals rules and patterns that can explain and predict at least some events in nature. Science enables us to take actions that affect events in the world around us. To make certain that scientific knowledge is used for the benefit of society, all of us must understand the nature of science—its strengths, its limitations, and its interactions with our culture.

DIFFERENTIATED INSTRUCTION

Struggling Students

Provide students with a prepared outline that includes the ten Big Ideas with several blank write-on lines below each one. Tell them to write important details about each Big Idea on the lines. Encourage students to rephrase information in their own words rather than copying information directly from the text.

Advanced Students

After students have completed their outlines, suggest they consider a topic of personal interest in biology, for example, biotechnology or insects. Then, have them write a paragraph identifying how at least two of the Big Ideas are related to their topic of interest. Have students share their paragraphs with the class.

Build Reading Skills

Suggest students use an outline to organize the information in Big Ideas in Biology. Model this for students by writing Cellular Basis of Life on the board. Under this, write the most important details from the paragraph in the text, such as “Living things are made of cells,” and “Some organisms consist of a single cell; others are made up of many cells.” Have students outline the remaining nine big ideas using the same format.
Global Ecology

Life on Earth is shaped by weather patterns and processes in the atmosphere so large that we are just beginning to understand them. We are also learning that activities of living organisms—including humans—profoundly affect both the atmosphere and climate. Humans now move more matter and use more energy than any other multicellular species on Earth. Global ecological studies, aided by satellite technology and supercomputers, are enabling us to learn about our global impact, which affects all life on Earth.

An ecologist studies lichens on Douglas fir. Many lichens are extremely sensitive to nitrogen- and sulfur-based air pollution. Thus, researchers often monitor lichens in efforts to study the effects of air pollution on forest health.

Fields of Biology

How do different fields of biology differ in their approach to studying life?

Living systems range from groups of molecules that make up cells to collections of organisms that make up the biosphere. Biology includes many overlapping fields that use different tools to study life from the level of molecules to the entire planet. Here’s a peek into a few of the smallest and largest branches of biology.

Quick Facts

Branches of Biology

The branches of biology are numerous. Zoologists, botanists, paleontologists, and ethologists are just a few of the great variety of biologists. Other biologists include biochemists, geneticists, cytologists, ecologists, and microbiologists. Biochemists study the chemistry of living things. Geneticists study heredity and variation among organisms. Cytologists, or cell biologists, study the structure and function of cells. Ecologists study the interactions of organisms in ecosystems. Microbiologists study the structure and function of microorganisms. The list goes on, and those mentioned are just the biologists who pursue knowledge in what is sometimes called theoretical science. There are also many biologists who work in applied or practical science, including physicians, medical researchers, wildlife managers, foresters, and agricultural researchers, to name just a few.
Biotechnology This field, created by the molecular revolution, is based on our ability to "edit" and rewrite the genetic code—in a sense, redesigning the living world to order. We may soon learn to correct or replace damaged genes that cause inherited diseases. Other research seeks to genetically engineer bacteria to clean up toxic wastes. Biotechnology also raises enormous ethical, legal, and social questions. Dare we tamper with the fundamental biological information that makes us human?

► A plant biologist analyzes genetically modified rice plants.

Building the Tree of Life Biologists have discovered and identified roughly 1.8 million different kinds of living organisms. That may seem like an incredible number, but researchers estimate that somewhere between 2 and 100 million more forms of life are waiting to be discovered around the globe—from caves deep beneath the surface, to tropical rainforests, to coral reefs and the depths of the sea. Identifying and cataloging all these life forms is enough work by itself, but biologists aim to do much more. They want to combine the latest genetic information with computer technology to organize all living things into a single universal "Tree of All Life"—and put the results on the Web in a form that anyone can access.

► A paleontologist studies signs of ancient life—fossilized dinosaur dung!

Ecology and Evolution of Infectious Diseases HIV, bird flu, and drug-resistant bacteria seem to have appeared out of nowhere, but the science behind their stories shows that relationships between hosts and pathogens are dynamic and constantly changing. Organisms that cause human disease have their own ecology, which involves our bodies, medicines we take, and our interactions with each other and the environment. Over time, disease-causing organisms engage in an "evolutionary arms race" with humans that creates constant challenges to public health around the world. Understanding these interactions is crucial to safeguarding our future.

► A wildlife biologist studies a group of wild gelada baboons. Pathogens in wild animal populations may evolve in ways that enable them to infect humans.

Genomics and Molecular Biology These fields focus on studies of DNA and other molecules inside cells. The "molecular revolution" of the 1980s created the field of genomics, which is now looking at the entire sets of DNA code contained in a wide range of organisms. Ever-more-powerful computer analyses enable researchers to compare vast databases of genetic information in a fascinating search for keys to the mysteries of growth, development, aging, cancer, and the history of life on Earth.

► A molecular biologist analyzes a DNA sequence.

Point out that some fields of biology described on these pages, such as genomics and molecular biology, did not exist until relatively recently. The development of new technology was instrumental in their creation. Other fields of biology described here, such as paleontology, have existed for many years, although they have been changed dramatically by new technology, as well.

Ask What are some ways that scientists in the fields of biology described on these pages use technology? (Sample answers: Molecular biologists use computers to analyze DNA sequences. Global ecologists use satellites to gather data.) Then, have students consider how the fields of biology described here are interconnected.

Ask How could a wildlife biologist use information generated by a molecular biologist? (Sample answer: A wildlife biologist could use information generated by a molecular biologist to find out if two similar-appearing species are genetically related.)

DIFFERENTIATED INSTRUCTION

Less Proficient Readers Use the photos on these pages to launch a discussion of fields of biology. Call on students to describe what they see in each picture. After students describe what they see, have them read the italicized sentence related to the photo. Then, ask them to use the picture, discussion, and sentence to write a sentence in their own words about each field of biology.

Check for Understanding

QUESTION BOARD
Establish a section of a bulletin board or white board in the classroom to be used by students to post anonymous questions about careers in biology or identify fields of biology about which they would like to learn more.

ADJUST INSTRUCTION
Read over students’ questions to identify common questions or topics of interest. Select several of these as topics for class discussion. Carefully examine the questions to determine if students have any misconceptions about the fields of biology described in the text. If so, address those by helping students review the correct information in the text.
LESSON 1.3

Build Math Skills

Tell students that using the metric system often involves conversions between metric units. For example, a measurement made in centimeters might need to be expressed in meters. To reinforce students’ ability to convert between units, write the following problems on the board:

- 1 kilometer = ? meters (1000)
- 0.45 liter = ? milliliters (450)
- 5000 milligrams = ? grams (5)
- 130 meters = ? kilometers (0.13)
- 2500 milliliters = ? liters (2.5)
- 0.017 grams = ? milligrams (17)

Challenge students to calculate the answers to these conversion problems.

DIFFERENTIATED INSTRUCTION

ELL Special Needs  Have students fold a piece of paper in half horizontally and then vertically to form four equal-sized squares. In each of the four squares, have them write one of the following terms: length, mass, volume, and temperature. Then, have them write the name of the metric unit used for each quantity in the appropriate box. Students can add pictures of tools used to measure each quantity or other visual reminders that help them remember this information.

ELL English Language Learners  Students who have recently moved to the U.S. may be more familiar with the metric system than students who have received most of their education in the U.S. Encourage these students to be the class “experts” on the metric system, by teaching a short lesson about it or by helping other students with the conversion problems listed above.

Have students access Data Analysis: Adventures in Measurement to explore strategies used by scientists when direct measurement is difficult.

Answers

FIGURE 1–15 The polar bear’s mass would be expressed in kilograms.

Quick Facts

THE INTERNATIONAL SYSTEM OF UNITS

The International Bureau of Weights and Measures, located near Paris, France, oversees the SI system of measurement. The Bureau recognizes seven official base units—meter (length), kilogram (mass), second (time), ampere (electric current), kelvin (temperature), candela (luminous intensity), and mole (amount of substance). Derived units are those that involve more than one base unit. For example, force is expressed in newtons, a unit derived using meters, kilograms, and seconds. Like all aspects of science, the base units and derived units recognized by the International Bureau of Weights and Measures are subject to additions and modifications as new technology and fields of scientific inquiry emerge.
**Safety** Scientists working in a laboratory or in the field are trained to use safe procedures when carrying out investigations. Laboratory work may involve flames or heating elements, electricity, chemicals, hot liquids, sharp instruments, and breakable glassware. Laboratory work and fieldwork may involve contact with living or dead organisms—not just potentially poisonous plants and venomous animals but also disease-carrying mosquitoes and water contaminated with dangerous microorganisms.

Whenever you work in your biology laboratory, you must follow safe practices as well. Careful preparation is the key to staying safe during scientific activities. Before performing any activity in this course, study the safety rules in Appendix B. Before you start each activity, read all the steps and make sure that you understand the entire procedure, including any safety precautions.

The single most important safety rule is to always follow your teacher’s instructions and directions in this textbook. Any time you are in doubt about any part of an activity, ask your teacher for an explanation. And because you may come in contact with organisms you cannot see, it is essential that you wash your hands thoroughly after every scientific activity. Remember that you are responsible for your own safety and that of your teacher and classmates. If you are handling live animals, you are responsible for their safety too.

---

**Assessment Answers**

1a. Living things are made up of one or more basic units called cells, are based on a universal genetic code, obtain and use material and energy, grow and develop, reproduce, respond to their environment, maintain a stable internal environment, and, as a group, change over time.

1b. A stimulus is a signal to which an organism responds. In this case, hunger is an internal stimulus, and the sight of the plum is an external stimulus.

2a. the cellular basis of life; information and heredity; matter and energy; growth, development, and reproduction; homeostasis; evolution; structure and function; unity and diversity of life; interdependence in nature; and science as a way of knowing

2b. Like all organisms, this newly discovered organism would consist of cells.

3a. Biologists study life from the level of molecules to the entire planet.

3b. Acceptable answers include ecology and wildlife biology.

4a. Scientists use a common system of measurement because they need to be able to replicate each other’s work, and many experiments involve quantitative data.

4b. Sample answer: If these scientists did not use a common system of measurement, they could inadvertently mix the wrong quantities of chemicals, which could potentially be dangerous.

5. 2.5 kg
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Using a Microscope to Estimate Size described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Students should use caution when handling the microscope slides.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 20.

Pre-Lab: Using a Microscope to Estimate Size

**Problem** How can you use a microscope to estimate the size of an object?

**Materials** compound microscope, transparent 15-cm plastic ruler, prepared slide of plant root or stem, prepared slide of bacteria

**Skills Focus** Observe, Measure, Calculate, Predict

**Connect to the** Big idea Science provides a way of knowing the world. The use of technology to gather data is a central part of modern science. In biology, the compound microscope is a vital tool. With a microscope, you can observe objects that are too tiny to see with the unaided eye. These objects include cells, which are the basis for all life.

In this lab, you will explore another important use of the microscope. You will use the microscope to estimate the size of cells.

**Background Questions**

a. **Explain** How did the invention of the microscope help scientists know the natural world?

b. **Explain** How can a microscope help a scientist use scientific methodology?

c. **Infer** List one important fact about life that scientists would not know without microscopes. *Hint: Review the characteristics of living things.*

**Pre-Lab Questions**

Preview the procedure in the lab manual.

1. **Review** Which lens provides more magnification—a low-power lens or a high-power lens? Which lens provides the larger field of view?

2. **Use Analogies** A photographer may take wide views and close-ups of the same scene. How are these views similar to the low-power and high-power lenses on a microscope? What is an advantage of each view?

3. **Calculate** Eight cells fit across a field of view of 160 μm. What is the width of each cell?

4. **Predict** Which cell do you think will be larger, the plant cell or the bacterial cell? Give a reason for your answer.

**PRE-LAB QUESTIONS**

1. The high-power lens provides more magnification. The low-power lens provides the larger field of view.

2. A wide view and low power can show the relationship between objects in space. A close-up and high-power lens can reveal more details about an object's structure.

3. 20 μm

4. Accept any answer for which a student provides a reason. For example, some students may predict that plant cells are smaller because a plant has more than one cell.

**Pre-Lab Answers**

**BACKGROUND QUESTIONS**

a. Sample answer: Microscopes allowed scientists to gather information about parts of the natural world that they could not previously observe.

b. Most students will say that microscopes help scientists observe and collect data. Some may know that microscopes can be used to conduct experiments.

c. Sample answer: Living things are made up of units called cells.
By applying scientific methodology, biologists can find answers to questions that arise in the study of life.

**1.1 What Is Science?**

One goal of science is to provide natural explanations for events in the natural world. Science also aims to use those explanations to understand patterns in nature and to make useful predictions about natural events.

Scientific methodology involves observing and asking questions, making inferences and forming hypotheses, conducting controlled experiments, collecting and analyzing data, and drawing conclusions.

<table>
<thead>
<tr>
<th>science</th>
<th>observation</th>
<th>hypothesis</th>
<th>controlled experiment</th>
</tr>
</thead>
</table>

Curiosity, skepticism, open-mindedness, and creativity help scientists generate new ideas.

Publishing peer-reviewed articles in scientific journals allows researchers to share ideas and to test and evaluate each other’s work.

In science, the word *theory* applies to a well-tested explanation that unifies a broad range of observations and hypotheses and that enables scientists to make accurate predictions about new situations.

Using science involves understanding its context in society and its limitations.

**1.2 Science in Context**

**1.3 Studying Life**

Living things are made up of units called cells, are based on a universal genetic code, obtain and use materials and energy, grow and develop, reproduce, respond to their environment, maintain a stable internal environment, and change over time.

The study of biology revolves around several interlocking big ideas: the cellular basis of life; information and heredity; matter and energy; growth, development, and reproduction; homeostasis; evolution; structure and function; unity and diversity of life; interdependence in nature; and science as a way of knowing.

Biology includes many overlapping fields that use different tools to study life from the level of molecules to the entire planet.

Most scientists use the metric system when collecting data and performing experiments.

<table>
<thead>
<tr>
<th>biology</th>
<th>asexual reproduction</th>
<th>assexual reproduction</th>
<th>metabolism</th>
</tr>
</thead>
</table>

**Answers**

**THINK VISUALLY**

1. Hypotheses
2. Observations
3. Field studies

**Performance Tasks**

**SUMMATIVE TASK** Have students recall from the first lesson of this chapter how Aristotle aimed to explain the world around him in terms of events and processes he could observe. Ask them to write a letter to Aristotle describing how science has changed and how it has stayed the same since his time. Challenge students to consider scientific methodology, available technology, and current fields of biology when writing their letters. Remind them to use the proper format for a friendly letter.

**TRANSFER TASK** Have students write an editorial for the school newspaper that encourages all students to take a science class, regardless of their anticipated career. In their editorial, students should explain how an informed public can make better decisions about issues involving science, and why a knowledge of science has become increasingly important in the society in which we live. Encourage students to submit their editorials to be considered for publication.

**STUDY ONLINE**

**REVIEW AND ASSESSMENT RESOURCES**

**Editable Worksheets** Pages of Study Workbooks A and B, Lab Manuals A and B, and the Assessment Resources Book are available online. These documents can be easily edited using a word-processing program.

**Lesson Overview** Have students reread the Lesson Overviews to help them study chapter concepts.

**Vocabulary Review** The Flash Cards and Crossword provide an interactive way to review chapter vocabulary.

**Chapter Assessment** Have students take an online version of the Chapter 1 Assessment.

**Standardized Test Prep** Students can take an online version of the Standardized Test Prep. You will receive their scores along with ideas for remediation.

**Diagnostic and Benchmark Tests** Use these tests to monitor your students’ progress and supply remediation.
Lesson 1.1

UNDERSTAND KEY CONCEPTS

1. c  2. a  3. b

4. c  5. b

6. The goals of science are to investigate and understand the natural world, to explain events in the natural world, and to use those explanations to make useful predictions.

7. An observation is made using senses to gather information; an inference is a logical interpretation based on prior knowledge and experience.

8. A hypothesis helps scientists understand the natural world by suggesting a testable explanation for a set of observations, which provides the starting point for discovering new information.

9. It makes sense for scientists to test just one variable at a time so that they can tell which variable is responsible for the results they observe.

10. In a controlled experiment, the experimental group is set up to test the effects of different variables (one variable at a time). The control group is exposed to the same conditions as the experimental group except for one independent variable.

11. When drawing a conclusion, scientists use data to support, refute, or revise their hypothesis. If the data indicate the researchers are generally correct but have a few of the details wrong, they may revise their hypothesis and retest it.

12. A graph can make patterns and trends in data easier to recognize and understand.

THINK CRITICALLY

13. Answers will vary. Students’ suggested experiments should include one independent variable and a control group. For example, find two young animals of the same species whose weight is approximately the same. Feed each animal a different food, and weigh the animals at intervals to find out which animal grows more quickly.

14. If other key variables are not controlled, there is no way of knowing which variable caused the observed results.

Lesson 1.2

UNDERSTAND KEY CONCEPTS

15. c  16. d  17. b

18. Scientific theories are useful because they unify a broad range of observations and enable scientists to make accurate predictions about many new situations.

19. While theories are supported by large amounts of evidence, they aren’t considered absolute truths because science is always changing—there is always the possibility that new evidence will require that a theory be modified or even discarded.

THINK CRITICALLY

20. Science is a process, or way of learning about the world, rather than a collection of unchanging facts.

21. Sample answer: Curiosity leads you to ask questions about the new skill; skepticism keeps you from accepting explanations without evidence; open-mindedness enables you to accept different ideas about how the skill could be learned; and creativity helps you explore different ways the skill could be learned.

22. Sample answer: I would look to see whether the researchers who wrote it showed any bias in their conclusions or made any mistakes in their techniques or reasoning. I would make sure their data supported their conclusions.
Lesson 1.3

UNDERSTAND KEY CONCEPTS

23. The process in which two cells from different parents unite to produce the first cell of a new organism is called
   a. homeostasis.
   b. development.
   c. asexual reproduction.
   d. sexual reproduction.

24. The process by which organisms keep their internal conditions relatively stable is called
   a. metabolism.
   b. a genome.
   c. evolution.
   d. homeostasis.

25. How are unicellular and multicellular organisms alike? How are they different?

26. Give an example of changes that take place as cells in a multicellular organism differentiate.

27. List three examples of stimuli that a bird responds to.

THINK CRITICALLY

28. Measure Use a ruler to find the precise length and width of this book in millimeters.

   (Hint: Refer to Appendix B.)
   1. (1) This symbol warns that the lab includes glassware that could be hazardous if broken. (2) This symbol is used to indicate the possibility of electric shock. (3) This symbol means that the lab involves the use of sharp objects that could cause injury. (4) This symbol is a reminder to use heat-resistant gloves when handling hot materials.

26. Sample answer: During growth and development, generalized cells become more and more different and specialized for particular functions. For example, specialized cells build tissues in the human body such as brain, muscle, and digestive tissues.

27. Answers may vary. Sample answer: the sounds of other birds, the sight of food, a cry from its offspring

THINK CRITICALLY

28. Check that students have reported their answers in centimeters. Students’ measurements should be close to the following: 220 mm x 283 mm.
Connecting Concepts

USE SCIENCE GRAPHICS

30. Graph 1 shows the number of organisms in the population increasing over time. Graph 2 shows an increase in the number of individuals in the population followed by a decrease, which results in no net change in the size of the population. Graph 3 shows several rapid increases in the number of individuals, each followed by a decrease in the number of individuals, resulting in no net change in the size of the population. Graph 4 shows a population that does not change in size over the time period represented in the graph.

31. Numerical values indicating time elapsed on the x-axis and number of organisms on the y-axis are needed.

32. Sample answer: The shape of Graph 1 could represent a chemical reaction in which a product accumulates, or it could represent the height of a plant over time.

WRITE ABOUT SCIENCE

33. Answers will vary. Students’ responses should describe how to use scientific methodology to determine what type of food a cat prefers. Students should include the following steps: observing and asking questions, inferring and hypothesizing, designing a controlled experiment, collecting and analyzing data, and drawing conclusions.

34. Students’ responses should include a testable hypothesis and a description of a controlled experiment in which the independent variable and the variables to be controlled are identified.

INTERPRET THE FOLLOWING GRAPH

35. Interpret Graphs The independent variable in the controlled experiment was the a. number of flies. b. number of groups studied. c. number of days. d. size of the containers.

36. Infer Which of the following is a logical inference based on the content of the graph? a. The flies in Group B were healthier than those in Group A. b. A fly population with more available space will grow larger than a population with less space. c. If Group B was observed for 40 more days, the size of the population would double. d. In 40 more days, the size of both populations would decrease at the same rate.
Standardized Test Prep

Multiple Choice

1. To ensure that a scientific work is free of bias and meets standards set by the scientific community, a research group’s work is peer reviewed by
   A anonymous scientific experts.
   B the general public.
   C the researchers’ friends.
   D lawmakers.
2. Which of the following characteristics is NOT shared by both a horse and the grass it eats?
   A uses energy
   B response to stimulus
   C movement from place to place
   D stable internal environment
3. Which of the following statements about a scientific theory is NOT true?
   A It has the same meaning in science as it does in daily life.
   B It enables scientists to make accurate predictions about new situations.
   C Scientific theories tie many hypotheses together.
   D It is based on a large body of evidence.
4. A bird-watcher sees an unusual bird at a feeder. He takes careful notes on the bird’s color, shape, and other physical features and then goes to a reference book to see if he can identify the species. What aspect of scientific thinking is most apparent in this situation?
   A observation
   B inference
   C hypothesis formation
   D controlled experimentation
5. Unlike sexual reproduction, asexual reproduction involves
   A two cells.  
   B two parents. 
   C one parent.  
   D one nonliving thing.
6. One meter is equal to
   A 1000 millimeters.
   B 1 millimeter.
   C 10 kilometers.
   D 1 milliliter.

Questions 7–8

Once a month, a pet owner recorded the mass of her puppy in a table. When the puppy was 3 months old, she started to feed it a “special puppy food” she saw advertised on TV.

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>Mass at Start of Month (kg)</th>
<th>Change in Mass per Month (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>+3</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>+5</td>
</tr>
</tbody>
</table>

7. According to the table, which statement is true?
   A The puppy’s mass increased at the same rate for each month shown.
   B The puppy’s mass was less than 5 kg at the start of the new diet.
   C The puppy gained 5 kg between age 3 and 4 months.
   D The puppy had gained 13 kg as a result of the new diet.
8. All of the following statements about the pet owner’s study are true EXCEPT
   A The owner used the metric system.
   B The owner recorded data.
   C The owner could graph the data.
   D The owner conducted a controlled experiment.

Open-Ended Response

9. Explain how a controlled experiment works.

If You Have Trouble With . . .

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>See Lesson</td>
<td>1.2</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.3</td>
<td>1.3</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

The Science of Biology 31

Test-Taking Tip

READ ALL THE ANSWER CHOICES

Tell students to be sure to read all of the answer choices on multiple-choice tests, even if the first choice seems to be correct. Remind them that a more-complete or better answer choice may be present among the remaining choices. By reading all of the answer choices, they are more likely to choose the best one.
Connect to the Big Idea

Have students look at the photograph of the polar bear in its icy habitat. Ask them what the bear’s habitat consists of. (mostly ice and water) Tell them that water is essential not only to polar bears but to all living things as it allows them to carry out basic life processes. This is because water has certain chemical properties that make it unique. Then, have students anticipate the answer to the question, What are the basic chemical principles that affect living things?

Have students read over the Chapter Mystery. Connect the Chapter Mystery to the Big Idea of Matter and Energy by explaining that most organisms—including ice fish—need oxygen for many body processes. For example, oxygen is needed to break down food molecules for energy. Ask students to predict how liquid blood could carry oxygen gas without hemoglobin to bind with the oxygen. As a hint, tell students that, in carbonated liquids, the bubbles they see are made up of carbon dioxide gas that has come out of the liquid.

Have students preview the chapter vocabulary terms using the Flash Cards.

Understanding by Design

Chapter 2 introduces the molecular basis of life, and thereby advances students’ comprehension of the Enduring Understanding: The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere. The Big Idea, Essential Question, and Guiding Questions, listed in the graphic organizer at the right, provide a framework for how students can explore the chemical principles that underlie life processes—from atoms to enzymes.

Performance Goals

In Chapter 2, students will use diagrams, lab activities, and analogies to learn about the chemistry of life. In the Chapter Mystery, they will apply basic chemical principles to understand how certain fish can survive without oxygen-carrying red blood cells. At the end of the chapter, students will demonstrate their understanding of the molecular basis of life by creating a storybook on the topic for a lower grade.
Water is locked in ice in the Svalbard islands of Norway—home to the polar bear. Even in such an extreme environment, organisms are able to obtain the matter and energy they need to survive.

**Chapter Mystery**

**The Ghostly Fish**

Most fish, just like you and other vertebrates, have red blood. Red blood cells carry oxygen, a gas essential for life. The cells’ red color comes from an oxygen-binding protein called hemoglobin.

But a very small number of fish don’t have such cells. Their blood is clear—almost transparent. Because they live in cold antarctic waters and have a ghostly appearance, they are nicknamed “ice fish.” How do these animals manage to survive without red blood cells?

As you read this chapter, look for clues to help you explain the ice fish’s unusual feature. Think about the chemistry that might be involved. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the fishy mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

**What’s Online**

Extend your reach by using these and other digital assets offered at Biology.com.

**Chapter Mystery**
In The Ghostly Fish, students can investigate the chemistry involved in an organism that lacks red blood cells.

**Untamed Science Video**
Follow the Untamed Science crew as they explore the unique chemistry of water.

**Art Review**
This drag-and-drop activity lets students explore ionic and covalent bonds.

**Art in Motion**
This animation shows the process of salt crystals dissolving in water.

**Data Analysis**
Students can analyze data about the ecological impact of acid rain.

**Visual Analogy**
Using this animation, students can further explore the lock-and-key analogy for an enzyme and its substrates.

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**Chapter 2**

**Big Idea:** Matter and Energy

**Chapter 2 EQ:** What are the basic chemical principles that affect living things?

2.1 GQ: What is the matter in organisms made of?

2.2 GQ: Why are the properties of water important to organisms?

2.3 GQ: How do organisms use different types of carbon compounds?

2.4 GQ: How do chemicals combine and break apart inside living things?
LESSON 2.1
The Nature of Matter

Getting Started

Objectives
2.1.1 Identify the three subatomic particles found in atoms.
2.1.2 Explain how all of the isotopes of an element are similar and how they are different.
2.1.3 Explain how compounds are different from their component elements.
2.1.4 Describe the two main types of chemical bonds.

Student Resources
Study Workbooks A and B, 2.1 Worksheets
Spanish Study Workbook, 2.1 Worksheets
Lab Manual A, 2.1 Quick Lab Worksheet
Lab Manual B, 2.1 Hands-On Activity Worksheet

For corresponding lesson in the Foundation Edition, see pages 28–32.

Key Questions
What three subatomic particles make up atoms?
How are all of the isotopes of an element similar?
In what ways do compounds differ from their component elements?
What are the main types of chemical bonds?

Vocabulary
atom • nucleus • electron • element • isotope • compound • ionic bond • ion • covalent bond • molecule • van der Waals forces

Taking Notes
Outline Before you read, make an outline of the major headings in the lesson. As you read, fill in main ideas and supporting details under each head.

FIGURE 2–1 A Carbon Atom

THINK ABOUT IT
What are you made of? Just as buildings are made from bricks, steel, glass, and wood, living things are made from chemical compounds. But it doesn’t stop there. When you breathe, eat, or drink, your body uses the substances in air, food, and water to carry out chemical reactions that keep you alive. If the first task of an architect is to understand building materials, then what would be the first job of a biologist? Clearly, it is to understand the chemistry of life.

Atoms
What three subatomic particles make up atoms?
The concept of the atom came first from the Greek philosopher Democritus, nearly 2500 years ago. Democritus asked a simple question: If you take an object like a stick of chalk and break it in half, are both halves still chalk? The answer, of course, is yes. But what happens if you break it in half again and again and again? Can you continue to divide without limit, or does there come a point at which you cannot divide the fragment of chalk without changing it into something else? Democritus thought that there had to be a limit. He called the smallest fragment the atom, from the Greek word atomos, which means “unable to be cut.”

Atoms are incredibly small. Placed side by side, 100 million atoms would make a row only about 1 centimeter long—about the width of your little finger! Despite its extremely small size, an atom contains subatomic particles that are even smaller. Figure 2–1 shows the subatomic particles in a carbon atom. The subatomic particles that make up atoms are protons, neutrons, and electrons.

Protons and Neutrons
Protons and neutrons have about the same mass. However, protons are positively charged particles (+) and neutrons carry no charge at all. Strong forces bind protons and neutrons together to form the nucleus, at the center of the atom.

Electrons
The electron is a negatively charged particle (−) with only 1/1840 the mass of a proton. Electrons are in constant motion in the space surrounding the nucleus. They are attracted to the positively charged nucleus but remain outside the nucleus because of the energy of their motion. Because atoms have equal numbers of electrons and protons, their positive and negative charges balance out, and atoms themselves are electrically neutral.

Teach for Understanding

ENDURING UNDERSTANDING The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

GUIDING QUESTION What is the matter in organisms made of?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand the chemical basis of the matter that makes up living things. Divide the class into groups, and ask each group to write a poem in which they answer the Key Questions of the lesson and use each of the lesson vocabulary terms. Give groups a chance to perform their poems for the class.
Elements and Isotopes

How are all of the isotopes of an element similar?

A chemical element is a pure substance that consists entirely of one type of atom. More than 100 elements are known, but only about two dozen are commonly found in living organisms. Elements are represented by one- or two-letter symbols. C, for example, stands for carbon, H for hydrogen, Na for sodium, and Hg for mercury. The number of protons in the nucleus of an element is called its atomic number. Carbon’s atomic number is 6, meaning that each atom of carbon has six protons and, consequently, six electrons. See Appendix E, The Periodic Table, which shows the elements.

Isotopes Atoms of an element may have different numbers of neutrons. For example, although all atoms of carbon have six protons, some have six neutrons, some seven, and a few have eight. Atoms of the same element that differ in the number of neutrons they contain are known as isotopes. The total number of protons and neutrons in the nucleus of an atom is called its mass number. Isotopes are identified by their mass numbers. Figure 2–3 shows the subatomic composition of carbon-12, carbon-13, and carbon-14 atoms. The weighted average of the masses of an element’s isotopes is called its atomic mass. “Weighted” means that the abundance of each isotope in nature is considered when the average is calculated. Because they have the same number of electrons, all isotopes of an element have the same chemical properties.

Radioactive Isotopes Some isotopes are radioactive, meaning that their nuclei are unstable and break down at a constant rate over time. The radiation these isotopes give off can be dangerous, but radioactive isotopes have a number of important scientific and practical uses.

Geologists can determine the ages of rocks and fossils by analyzing the isotopes found in them. Radiation from certain isotopes can be used to detect and treat cancer and to kill bacteria that cause food to spoil. Radioactive isotopes can also be used as labels or “tracers” to follow the movements of substances within organisms.

In Your Notebook Draw a diagram of a helium atom, which has an atomic number of 2.

Isotopes of Carbon

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Number of Protons</th>
<th>Number of Electrons</th>
<th>Number of Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon-12 (nonradioactive)</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Carbon-13 (nonradioactive)</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Carbon-14 (radioactive)</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

Radioactive Isotopes

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How Science Works

THE SAME YET DIFFERENT

In the early nineteenth century, British chemist John Dalton proposed several highly significant postulates about matter. One of Dalton’s postulates was that all atoms of a given element are identical. About a century later, scientists working on radioactive decay discovered that many atoms seemed to refute Dalton’s postulate. For example, another British chemist and physicist, Francis Aston, found that neon atoms can have a mass number of either 20 or 22. He suggested that atoms with both mass numbers should be considered neon, given that they both have the same number of protons and differ only in their number of neutrons. He called them isotopes, based on a term coined earlier by the British chemist Frederick Soddy. Soddy had conceived of the idea of isotopes (from the Greek words for “same” and “place”) to describe different atoms that could occupy the same place in the periodic table.

Teach

Use Models

Have students model isotopes using beads of two different colors to represent protons and neutrons. Tell them to place six beads of one color and six beads of the other color together in a pile on their desk. Explain that each pile of beads represents the nucleus of a carbon-12 atom. Then, tell students to select more beads as needed to model the nuclei of carbon-13 and carbon-14 isotopes.

Ask How many protons does each isotope have? (six) How many electrons? (six)

Add a proton bead to a student’s model of carbon-14.

Ask Do the beads still model the nucleus of a carbon isotope? (No; carbon isotopes have six protons.)

DIFFERENTIATED INSTRUCTION

Struggling Students Have students use a different element to make sure they understand the general relationship between atoms and isotopes. Tell students that an atom of helium has two protons and two neutrons in its nucleus.

Ask How many protons and neutrons are in the nucleus of the isotope helium-5? (two protons and three neutrons)

Ask How many electrons do helium and helium-5 have? (two)

Focus on ELL: Extend Language

BEGINNING AND INTERMEDIATE SPEAKERS

Have students use a different element to make sure they understand the general relationship between atoms and isotopes. Tell students that an atom of helium has two protons and two neutrons in its nucleus.

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Ask How many electrons do helium and helium-5 have? (two)

ANSWERS

FIGURE 2–3 carbon-14

IN YOUR NOTEBOOK Students’ diagrams should resemble Figure 2–1 but show an atom with two protons, two neutrons, and two electrons.
Build Science Skills

Demonstrate how different chemical compounds that contain the same elements may vary in their properties. Place tap water in a beaker labeled \( H_2O \) and a dilute solution of hydrogen peroxide in a beaker labeled \( H_2O_2 \). As students observe, pour a few drops of each liquid onto two pieces of the same colored fabric. Students will see that the water only wets the fabric, while the hydrogen peroxide bleaches it. Challenge students to infer why the two compounds behave so differently, even though they contain the same elements. (The elements are combined in different proportions in the two compounds, which gives each compound different chemical properties.)

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** To further help students discern compounds and elements, have them make a **Vocabulary Word Map** for the term **compound**. Their word maps for **compound** might include such attributes as **combination of two or more elements, elements in definite proportions, unique physical and chemical properties, and atoms held together by chemical bonds**. Then, have them make another word map for **element**. Have pairs of students discuss the difference between the two terms.


**Address Misconceptions**

**Atomic Models** The use of atomic models, like the Bohr models in Figure 2–4, can lead to student misconceptions. For example, students may think that electrons travel in fixed orbits around the nucleus of an atom, similar to the way planets revolve around the sun. Rather, electrons travel about in an electron cloud—a “fuzzy” area around the nucleus where electrons are only *likely* to be found. Help them appreciate that models are just representations, not reality. Use the analogy of a model car to make this point by discussing as a class how a model car differs from a real car. Then, explain some of the ways that simple atomic models differ from real atoms.

**Chemical Compounds**

- **In what ways do compounds differ from their component elements?**

In nature, most elements are found combined with other elements in compounds. A chemical **compound** is a substance formed by the chemical combination of two or more elements in definite proportions. Scientists show the composition of compounds by a kind of shorthand known as a chemical formula. Water, which contains two atoms of hydrogen for each atom of oxygen, has the chemical formula \( H_2O \). The formula for table salt, \( NaCl \), indicates that the elements that make up table salt—sodium and chlorine—combine in a 1:1 ratio.

- **The physical and chemical properties of a compound are usually very different from those of the elements from which it is formed.** For example, hydrogen and oxygen, which are gases at room temperature, can combine explosively and form liquid water. Sodium is a silver-colored metal that is soft enough to cut with a knife. It reacts explosively with water. Chlorine is very reactive, too. It is a poisonous, yellow-greenish gas that was used in battles during World War I. Sodium chloride, table salt, is a white solid that dissolves easily in water. As you know, sodium chloride is not poisonous. In fact, it is essential for the survival of most living things.

**Chemical Bonds**

- **What are the main types of chemical bonds?**

The atoms in compounds are held together by various types of chemical bonds. Much of chemistry is devoted to understanding how and when chemical bonds form. Bond formation involves the electrons that surround each atomic nucleus. The electrons that are available to form bonds are called valence electrons. **The main types of chemical bonds are ionic bonds and covalent bonds.**

### Model an Ionic Compound

1. You will be assigned to represent either a sodium atom or a chlorine atom.
2. Obtain the appropriate number of popcorn kernels to represent your electrons.
3. Find a partner with whom you can form the ionic compound sodium chloride—table salt.
4. In table salt, the closely packed sodium and chloride ions form an orderly structure called a crystal. With all your classmates, work as a class to model a sodium chloride crystal.

### Analyze and Conclude

1. **Relate Cause and Effect** Describe the exchange of popcorn kernels (electrons) that took place as you formed the ionic bond. What electrical charges resulted from the exchange?
2. **Use Models** How were the “ions” arranged in the model of the crystal? Why did you and your classmates choose this arrangement?

**Quick Lab**

**PURPOSE** Students will model the attraction between oppositely charged ions in an ionic compound.

**MATERIALS** bags of popcorn kernels, paper

**SAFETY** Tell students not to eat any of the popcorn kernels and to wash their hands after they finish the lab.

**PLANNING** Review how bonds hold together the atoms in compounds. Have students create labels for themselves—either Na or Cl—that they then hold up during the activity.

**ANALYZE AND CONCLUDE**

1. Students representing Na lose one kernel and become positive. Students representing Cl gain one kernel and become negative.
2. Sample answer: We huddled close together to represent Na+ ions surrounding Cl– ions, and Cl– ions surrounding Na+ ions. Describe how the ions are closely packed to form a crystal lattice.
ionic bond

An **ionic bond** is formed when one or more electrons are transferred from one atom to another. Recall that atoms are electrically neutral because they have equal numbers of protons and electrons. An atom that loses electrons becomes positively charged. An atom that gains electrons has a negative charge. These positively and negatively charged atoms are known as **ions**.

Figure 2–4A shows how ionic bonds form between sodium and chlorine in table salt. A sodium atom easily loses its one valence electron and becomes a sodium ion (Na⁺). A chlorine atom easily gains an electron and becomes a chloride ion (Cl⁻). In a salt crystal, there are trillions of sodium and chloride ions. These oppositely charged ions have a strong attraction, forming an **ionic bond**.

**Covalent Bonds** Sometimes electrons are shared by atoms instead of being transferred. What does it mean to share electrons? It means that the moving electrons actually travel about the nuclei of both atoms, forming a **covalent bond**. When the atoms share two electrons, the bond is called a single covalent bond. Sometimes the atoms share four electrons and form a double bond. In a few cases, atoms can share six electrons, forming a triple bond. The structure that results when atoms are joined together by covalent bonds is called a molecule. The **molecule** is the smallest unit of most compounds. The diagram of a water molecule in Figure 2–4B shows that each hydrogen atom is joined to water’s lone oxygen atom by a single covalent bond. When atoms of the same element join together, they also form a molecule. Oxygen molecules in the air you breathe consist of two oxygen atoms joined by covalent bonds.

**In Your Notebook** In your own words, describe the differences between ionic and covalent bonds.

**Check for Understanding**

**VISUAL REPRESENTATION**

Ask small groups of students to create a **Concept Map** that relates the following concepts: atom, proton, neutron, electron, element, isotope, compound, ionic bond, ion, covalent bond, and molecule.


**ADJUST INSTRUCTION**

If students’ concept maps are incorrect or show that they are confused, have students work in small groups. Ask group members to compare concept maps. If they disagree about how any of the concepts are related, have them refer to the text.

**LESSON 2.1**

**Build Study Skills**

Use familiar phenomena as analogies to help students understand and distinguish between ionic and covalent bonds. After students have read about the two types of bonds, explain that ionic bonding can be summed up as “opposites attract.” Electrons are transferred from one atom to the other, forming positive and negative ions that attract and bind with one another like the north and south poles of two magnets. You may want to use magnets to demonstrate this type of attraction. Then, explain that covalent bonding involves the sharing of electrons. When electrons are shared between atoms, the atoms bind together like two people sharing the same umbrella. Challenge students to think of other analogies for covalent bonds in which two people or objects are held together by sharing something between them.

**DIFFERENTIATED INSTRUCTION**

**Less Proficient Readers** Have students work together in pairs to make a **Venn Diagram** for ionic and covalent bonds. Similarities might include that they hold atoms together. Differences might include that ionic bonds involve the transfer of electrons, whereas covalent bonds involve the sharing of electrons.


**Advanced Students** Challenge creative students to develop three-dimensional or computer-generated models of ionic and covalent bonds. Their models should show how the two types of bonds form and how they differ. Ask students to present their models to the class.

Students should respond that the atoms in an oxygen molecule are joined together by covalent bonds. Ask them to predict what factors might affect how much oxygen will dissolve in water. Students can go online to **Biology.com** to gather their evidence.

**Students can use drag-and-drop labels to further explore ionic and covalent bonding in Art Review: Ionic and Covalent Bonding.**

**Answers**

**IN YOUR NOTEBOOK** Ionic bonds are formed when electrons are transferred from one atom to another. Covalent bonds are formed when atoms share electrons, which hold the atoms together in a molecule.
Assess and RemEDIATE

EVALUATE UNDERSTANDING

Write the chemical formula for water (H₂O) on the board. Then, ask students to draw and label a model of a water molecule that shows how the atoms in a water molecule “stick” together. (Students should make and label a drawing similar to Figure 2–4B.) Then, have them complete the 2.1 Assessment.

REMEDICATION SUGGESTION

1a. Struggling Students If students have trouble with Question 5, have them reread the first paragraph of the lesson.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. An atom is an extremely small particle with a nucleus in the center. The nucleus is formed of smaller particles called protons, which are positively charged, and neutrons, which have no charge. Smaller particles called electrons, which are negatively charged, are in constant motion in the space surrounding the nucleus.

1b. 20 electrons

2a. because they all have the same number of protons and electrons

2b. Carbon-12 and carbon-14 each have six protons and six electrons. However, carbon-12 has six neutrons, whereas carbon-14 has eight neutrons.

3a. a substance formed by the chemical combination of two or more elements in definite proportions

3b. The two compounds have different properties because they contain hydrogen and oxygen in different proportions.

4a. ionic bonds and covalent bonds

4b. an ionic bond

5. Why do you think it is important that biologists have a good understanding of chemistry?

Big idea

Matter and Energy

Chapter 2 • Lesson 1

Van der Waals Forces Because of their structures, atoms of different elements do not all have the same ability to attract electrons. Some atoms have a stronger attraction for electrons than do other atoms. Therefore, when the atoms in a covalent bond share electrons, the sharing is not always equal. Even when the sharing is equal, the rapid movement of electrons can create regions on a molecule that have a tiny positive or negative charge.

When molecules are close together, a slight attraction can develop between the oppositely charged regions of nearby molecules. Chemists call such intermolecular forces of attraction van der Waals forces, after the scientist who discovered them. Although van der Waals forces are not as strong as ionic bonds or covalent bonds, they can hold molecules together, especially when the molecules are large.

FIGURE 2–5 The underside of each foot on this Tokay gecko is covered by millions of tiny hairlike projections. The projections themselves are made of even finer fibers, creating more surface area for “sticking” to surfaces at the molecular level. This allows geckos to scurry up walls and across ceilings.

SEM 950
A Nature-Inspired Adhesive

People who keep geckos as pets have always marveled at the way these little lizards can climb up vertical surfaces, even smooth glass walls, and then hang on by a single toe despite the pull of gravity. How do they do it? No, they do not have some sort of glue on their feet and they don’t have suction cups. Incredibly, they use van der Waals forces.

A gecko foot is covered by as many as half a million tiny hairlike projections. Each projection is further divided into hundreds of tiny, flat-surfaced fibers. This design allows the gecko’s foot to come in contact with an extremely large area of the wall at the molecular level. Van der Waals forces form between molecules on the surface of the gecko’s foot and molecules on the surface of the wall. This allows the gecko to actually balance the pull of gravity.

If it works for the gecko, why not for us? That’s the thinking of researchers at the Massachusetts Institute of Technology, who have now used the same principle to produce a bandage. This new bandage is held to tissue by van der Waals forces alone. Special materials make it possible for the new bandage to work even on moist surfaces, which means that it may be used to reseal internal tissues after surgery. By learning a trick or two from the gecko, scientists may have found a way to help heal wounds, and even save lives in the process.

Suppose you are a doctor reviewing this new bandage for its potential applications. In what ways might you use such a bandage? Present your ideas as a list.

Quick Facts

**NANOSTRUCTURE BANDAGES**

The bandage described in the feature is covered with nanostructures—like those on a gecko’s foot—that dramatically increase the amount of surface area in contact with the body and, thus, the strength of van der Waals forces holding it in place. The developers of the bandage have tested it in living tissues and found that it is twice as strong as bandages without nanostructures. In addition to its superior adhesion, even on wet tissues, the bandage is waterproof. It is also biodegradable, so it does not have to be removed after surgery. It is biocompatible, as well, which means that it does not cause allergic reactions or other tissue responses. Because it is elastic, the bandage can conform to the irregular shapes of organs and other body structures. It can also be used as a patch to deliver healing medications directly to tissues.
Getting Started

**Objectives**

2.2.1 Discuss the unique properties of water.
2.2.2 Differentiate between solutions and suspensions.
2.2.3 Explain what acidic solutions and basic solutions are.

**Student Resources**

Study Workbooks A and B, 2.2 Worksheets
Spanish Study Workbook, 2.2 Worksheets

**Build Background**

Play a guessing game with the class to build background about water and its importance to living things. Tell students the following statements. After each, give volunteers a chance to guess what “it” is.

- We take it for granted, but there would be no life on Earth without it.
- It makes up about 60 percent of the human body.
- It is nicknamed the “universal solvent.”

**UNIFYING CONCEPTS AND PROCESSES**

I, III

**CONTENT**

B.1, B.2, B.3, B.4

**INQUIRY**

A.1.b

**THINK ABOUT IT**

Looking back at our beautiful planet, an astronaut in space said that if other beings have seen the Earth, they must surely call it “the blue planet.” He referred, of course, to the oceans of water that cover nearly three fourths of Earth’s surface. The very presence of liquid water tells a scientist that life may also be present on such a planet. Why should this be so? Why should life itself be connected so strongly to something so ordinary that we often take it for granted? The answers to those questions suggest that there is something very special about water and the role it plays in living things.

**The Water Molecule**

**How does the structure of water contribute to its unique properties?**

Water is one of the few compounds found in a liquid state over most of the Earth’s surface. Like other molecules, water (H₂O) is neutral. The positive charges on its 10 protons balance out the negative charges on its 10 electrons. However, there is more to the story.

**Polarity**

With 8 protons in its nucleus, an oxygen atom has a much stronger attraction for electrons than does a hydrogen atom with its single proton. Thus, at any moment, there is a greater probability of finding the shared electrons in water close to its oxygen atom than near its hydrogen atoms. Because of the angles of its chemical bonds, the oxygen atom is on one end of the molecule and the hydrogen atoms are on the other, as shown in Figure 2–6. As a result, the oxygen end of the molecule has a slight negative charge and the hydrogen end of the molecule has a slight positive charge.

A molecule in which the charges are unevenly distributed is said to be “polar,” because the molecule is a bit like a magnet with two poles. The charges on a polar molecule are written in parentheses, (–) or (+), to show that they are weaker than the charges on ions such as Na⁺ and Cl⁻.

**Vocabulary**

hydrogen bond • cohesion • adhesion • mixture • solution • solute • solvent • suspension • pH scale • acid • base • buffer

**Taking Notes**

**Venn Diagram**

As you read, draw a Venn diagram showing the differences between solutions and suspensions and the properties that they share.

**FIGURE 2–6 A Water Molecule**

A water molecule is polar because there is an uneven distribution of electrons between the oxygen and hydrogen atoms. The negative pole is near the oxygen atom and the positive pole is between the hydrogen atoms.

**Teach for Understanding**

**ENDURING UNDERSTANDING**

The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

**GUIDING QUESTION**

Why are the properties of water important to organisms?

**EVIDENCE OF UNDERSTANDING**

After completing the lesson, give students the following assessment to show they understand the properties of water that are important to organisms. Have pairs of students create three labeled diagrams to illustrate: (1) why water molecules are polar, (2) how they form hydrogen bonds, and (3) how they dissolve other polar or ionic substances.
Hydrogen Bonding Because of their partial positive and negative charges, polar molecules such as water can attract each other. The attraction between a hydrogen atom on one water molecule and the oxygen atom on another is known as a hydrogen bond. Hydrogen bonds are not as strong as covalent or ionic bonds, and they can form in other compounds as well. Because water is a polar molecule, it is able to form multiple hydrogen bonds, which account for many of water’s special properties.

Cohesion Cohesion is an attraction between molecules of the same substance. Because a single water molecule may be involved in as many as four hydrogen bonds at the same time, water is extremely cohesive. Cohesion causes water molecules to be drawn together, which is why drops of water form beads on a smooth surface. Cohesion also produces surface tension, explaining why some insects and spiders can walk on a pond’s surface, as shown in Figure 2-7.

Adhesion On the other hand, adhesion is an attraction between molecules of different substances. Have you ever been told to read the volume in a graduated cylinder at eye level? As shown in Figure 2-8, the surface of the water in the graduated cylinder dips slightly in the center because the adhesion between water molecules and glass molecules is stronger than the cohesion between water molecules. Adhesion between water and glass also causes water to rise in a narrow tube against the force of gravity. This effect is called capillary action. Capillary action is one of the forces that draws water out of the roots of a plant and up into its stems and leaves. Cohesion holds the column of water together as it rises.

Heat Capacity Another result of the multiple hydrogen bonds between water molecules is that it takes a large amount of heat energy to cause those molecules to move faster, which raises the temperature of the water. Therefore, water’s heat capacity, the amount of heat energy required to increase its temperature, is relatively high. This allows large bodies of water, such as oceans and lakes, to absorb large amounts of heat with only small changes in temperature. The organisms living within are thus protected from drastic changes in temperature. At the cellular level, water absorbs the heat produced by cell processes, regulating the temperature of the cell.

In Your Notebook Draw a diagram of a meniscus. Label where cohesion and adhesion occur.

FIGURE 2-8 Adhesion Adhesion between water and glass molecules is responsible for causing the water in these columns to rise. The surface of the water in the glass column dips slightly in the center, forming a curve called a meniscus.

Quick Facts

WATER AND LIFE ON EARTH

In addition to the properties described in the text, water has other unique properties that are important to life on Earth. One property is its high boiling point. Because of this property, water remains in a liquid state over most of Earth’s surface. This is crucial for life, because virtually all organisms need liquid water to survive. Unlike most other compounds, water is less dense as a solid than it is as a liquid. This causes ice to float on water in temperate zone lakes in the winter. The floating ice insulates the water beneath it and prevents it from freezing. This, in turn, allows aquatic organisms that live in the water to survive during cold weather.

Answers

FIGURE 2-7 The hydrogen atoms have a slight negative charge, and the oxygen atoms have a slight positive charge.

IN YOUR NOTEBOOK Diagrams should resemble Figure 2-8, with the meniscus curving downward. Arrows should point to where water meets glass (adhesion), and to the water (cohesion).
Build Science Skills

Point out that solutes like table salt (NaCl) seem to disappear when they dissolve in water. You may wish to demonstrate this by dissolving salt in a beaker of water. Call on a volunteer to explain why the salt seems to disappear. (Its ions break apart and move throughout the water, so they no longer form visible, solid crystals.) Have students predict what happens to the mass and volume of water when salt is dissolved in it. (Both increase.)

Ask Besides tasting the water, how could you show that the salt is still there even though you can no longer see it? (You could measure the mass or volume of the water before and after salt is added.)

DIFFERENTIATED INSTRUCTION

Struggling Students To better understand the concept of solution, have students focus on the Na+ and Cl– ions in the beaker at right in Figure 2–9. Suggest students draw a simple diagram showing a solution in which all the salt has dissolved. (Each Na+ and Cl– ion is surrounded by water molecules. The ions are evenly distributed throughout the solution.)

Students should conclude that the cold temperature of antarctic waters would increase the amount of dissolved oxygen available for ice fish. Explain that oxygen dissolves in water when oxygen molecules are surrounded by water molecules. Challenge students to infer why more oxygen molecules dissolve in water at lower temperatures. (At lower temperatures, oxygen molecules have less energy on average and are less likely to escape the effects of intermolecular attractions in the solution.) Students can go online to Biology.com to gather their evidence.

Answers

FIGURE 2–9 The ions are surrounded by water molecules, separating the sodium and chloride in solution. Eventually, the ions become evenly distributed throughout the solution.

Solutions and Suspensions

How does water’s polarity influence its properties as a solvent?

Water is not always pure; it is often found as part of a mixture. A mixture is a material composed of two or more elements or compounds that are physically mixed together but not chemically combined. Salt and pepper stirred together constitute a mixture. So does sugar and sand. Earth’s atmosphere is a mixture of nitrogen, oxygen, carbon dioxide, and other gases. Living things are in part composed of mixtures involving water. Two types of mixtures that can be made with water are solutions and suspensions.

Solutions If a crystal of table salt is placed in a glass of warm water, sodium and chloride ions on the surface of the crystal are attracted to the polar water molecules. Ions break away from the crystal and are surrounded by water molecules, as illustrated in Figure 2–9. The ions gradually become dispersed in the water, forming a type of mixture called a solution. All the components of a solution are evenly distributed throughout the solution. In a saltwater solution, table salt is the solute—the substance that is dissolved. Water is the solvent—the substance in which the solute dissolves. Water’s polarity gives it the ability to dissolve both ionic compounds and other polar molecules.

Water easily dissolves salts, sugars, minerals, gases, and even other solvents such as alcohol. Without exaggeration, water is the greatest solvent on Earth. But even water has limits. When a given amount of water has dissolved all of the solute it can, the solution is said to be saturated.

Suspensions Some materials do not dissolve when placed in water, but separate into pieces so small that they do not settle out. The movement of water molecules keeps the small particles suspended. Such mixtures of water and nondissolved material are known as suspensions. Some of the most important biological fluids are both solutions and suspensions. The blood that circulates through your body is mostly water. The water in the blood contains many dissolved compounds. However, blood also contains cells and other undissolved particles that remain in suspension as the blood moves through the body.

FIGURE 2–9 A Salt Solution When an ionic compound such as sodium chloride is placed in water, water molecules surround and separate the positive and negative ions. Interpret Visuals What happens to the sodium ions and chloride ions in the solution?

UbD Check for Understanding

USE VOCABULARY

Divide the class into small groups, and ask students in each group to work together to create an acrostic poem based on the vocabulary term polar. (An acrostic poem is a poem in which the first letter of each line spells out another message.) Their poems should state facts about water that are due to its polarity, such as “P: Possible to dissolve many substances easily.”

ADJUST INSTRUCTION

If students’ acrostics reveal they are confused by the polar nature of water, have them write two quick summary sentences. These sentences should explain how water’s polarity affects its ability to form hydrogen bonds and dissolve other polar molecules. Have pairs share their summaries and then work together to write a new acrostic poem.
Acids, Bases, and pH

Why is it important for cells to buffer solutions against rapid changes in pH?

Water molecules sometimes split apart to form ions. This reaction can be summarized by a chemical equation in which double arrows are used to show that the reaction can occur in either direction.

\[
\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-
\]

How often does this happen? In pure water, about 1 water molecule in 550 million splits to form ions in this way. Because the number of positive hydrogen ions produced is equal to the number of negative hydroxide ions produced, pure water is neutral.

The pH Scale

Chemists devised a measurement system called the pH scale to indicate the concentration of \(\text{H}^+\) ions in solution. As Figure 2–10 shows, the pH scale ranges from 0 to 14. At a pH of 7, the concentration of \(\text{H}^+\) ions and \(\text{OH}^-\) ions is equal. Pure water has a pH of 7. Solutions with a pH below 7 are called acidic because they have more \(\text{H}^+\) ions than \(\text{OH}^-\) ions. The lower the pH, the greater the acidity. Solutions with a pH above 7 are called basic because they have more \(\text{OH}^-\) ions than \(\text{H}^+\) ions. The higher the pH, the more basic the solution. Each step on the pH scale represents a factor of 10. For example, a liter of a solution with a pH of 4 has 10 times as many \(\text{H}^+\) ions as a liter of a solution with a pH of 5.

FIGURE 2–10 The pH Scale

The concentration of \(\text{H}^+\) ions determines whether solutions are acidic or basic. The most acidic material on this pH scale is stomach acid. The most basic material on this scale is oven cleaner.

In Your Notebook Order these items in order of increasing acidity: soap, lemon juice, milk, acid rain.

Acidic and Basic Foods

Order the list of food and drink samples in order of increasing acidity.

1. Predict whether the food samples provided are acidic or basic.
2. Tear off a 2-inch piece of pH paper for each sample you will test. Place these pieces on a paper towel.
3. Construct a data table in which you will record the name and pH of each food sample.

Quick Lab

Purpose Students will make and test predictions about which foods are acidic and which are basic.

Materials solid foods and fruit juices, pH paper, paper towel, scalpel, dropper pipette

Safety Warn students to handle scalpels with care. Remind them not to eat any of the foods tested in the lab.

Planning Prepare small samples of a variety of solid foods and fruit juices. Most foods are at least slightly acidic, but there are a few exceptions, including egg white and tofu. You may want to include one of these foods. If you use egg white, cook it first to kill any bacteria. Items can be placed in small, paper sample cups available from restaurant or party supply stores.

Analyze and Conclude

1. Answers will vary depending on the food and juice samples tested.
2. Students’ predictions were correct if they agree with the pH test results.

Address Misconceptions

Corrosive Properties of Bases Most students know that strong acids are harsh solutions that may “eat away” other substances, but many do not realize that bases can be corrosive too. Show the class a bottle of drain cleaner. Point out that it contains sodium hydroxide, a base. Sodium hydroxide will “eat away” at the clog, eliminating it.

Answers

IN YOUR NOTEBOOK soap, milk, acid rain, lemon juice

Use Visuals

Use Figure 2–10 to familiarize students with acids, bases, and pH. Point out that pH is a measure of hydrogen ion concentration. Then, explain that acids have a higher hydrogen ion concentration and bases a lower hydrogen ion concentration than pure water. Have students find the value for pure water on the pH scale. After explaining that the pH of pure water is the point of neutrality on the scale, have students find the pH of stomach acid and bleach.

Ask How does the hydrogen ion concentration of stomach acid and bleach compare with that of pure water? (H⁺ ion concentration is higher for stomach acid and lower for bleach.)

Differentiated Instruction

Struggling Students It may seem counterintuitive to students that pH, which measures hydrogen ion concentration, decreases as the hydrogen ion concentration increases. To reinforce the fact that hydrogen ion concentration and pH have an inverse relationship, have students create a simple, Two-Column Table to help them remember the relationship between pH and hydrogen ion concentration. Students should make a column for pH and another for Hydrogen ion concentration. Then, ask them to fill in “high” and “low” accordingly in the table, to show that low pH = high H⁺ concentration, and high pH = low H⁺ concentration.

Study Wkbks A/B, Appendix S31, Two-Column Table. Transparencies, GO16.

Have students access Data Analysis: Acid Rain to use data to learn more about the ecological impact of acid rain.
LESSON 2.2

Connect to Health Science

Explain that normal blood pH is between 7.35–7.45. A lower or higher blood pH can be a sign of ill health. Have students discuss why regulating blood pH is vital to maintaining homeostasis.

DIFFERENTIATED INSTRUCTION

**Advanced Students** Explain that the acidity of blood is reduced by the actions of the kidneys and lungs. The kidneys filter out and excrete excess H+ ions from the blood, while the lungs exhale more CO2 when blood acid levels are high. Ask students how blood pH might be affected by a disease that reduced lung function. *(The blood might be more acidic.)*

Assess and Remediate

**EVALUATE UNDERSTANDING**

Have students write a paragraph that explains how the concentration of hydrogen ions determines the acid-base properties of a solution. Then, have them complete the 2.2 Assessment.

**REMEDIAION SUGGESTION**

**Special Needs** If students have difficulty answering Question 1c, remind them that a polar molecule is like a magnet: it has a positive end and a negative end. Then, have them study Figure 2–7.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. A molecule is polar when there is an uneven distribution of electrons between its atoms. This causes the molecule to have an area with a slight negative charge and an area with a slight positive charge.

1b. A hydrogen bond occurs when the slight positive charge on a hydrogen atom in one water molecule is attracted to the slight negative charge on the oxygen atom in another water molecule.

1c. With eight protons in its nucleus, the oxygen atom in a water molecule has a much stronger attraction for electrons than do the hydrogen atoms in the molecule. The oxygen atom is on one end of the molecule, and the hydrogen atoms are on the other end. Therefore, the oxygen end of the molecule is slightly negative while the hydrogen end is slightly positive—resulting in a polar molecule.

2a. Water is such a good solvent because of its polarity. It can dissolve both ionic compounds and other polar molecules.

2b. A solution is a mixture of two or more substances in which the molecules of the substances are evenly distributed. A suspension is a mixture of water and nondissolved materials.

2c. During exercise, many chemical changes occur in the body, including a drop in blood pH, which can be very serious. How is the body able to cope with such changes?

**WRITE ABOUT SCIENCE**

4. Suppose you are a writer for a natural history magazine for children. This month’s issue will feature insects. Write a paragraph explaining why some bugs, such as the water strider, can walk on water.
2.3  Carbon Compounds

THINK ABOUT IT  In the early 1800s, many chemists called the compounds created by organisms “organic,” believing they were fundamentally different from compounds in nonliving things. Today, we understand that the principles governing the chemistry of living and nonliving things are the same, but the term “organic chemistry” is still around. Today, organic chemistry means the study of compounds that contain bonds between carbon atoms, while inorganic chemistry is the study of all other compounds.

The Chemistry of Carbon

What elements does carbon bond with to make up life’s molecules?

Why is carbon so interesting that a whole branch of chemistry should be set aside just to study carbon compounds? There are two reasons for this. First, carbon atoms have four valence electrons, allowing them to form strong covalent bonds with many other elements. Carbon can bond with many elements, including hydrogen, oxygen, phosphorus, sulfur, and nitrogen to form the molecules of life. Living organisms are made up of molecules that consist of carbon and these other elements.

Even more important, one carbon atom can bond to another, which gives carbon the ability to form chains that are almost unlimited in length. These carbon-carbon bonds can be single, double, or triple covalent bonds. Chains of carbon atoms can even close up on themselves to form rings, as shown in Figure 2–12. Carbon has the ability to form millions of different large and complex structures. No other element even comes close to matching carbon’s versatility.

FIGURE 2–12 Carbon Structures  Carbon can form single, double, or triple bonds with other carbon atoms. Each line between atoms in a molecular drawing represents one covalent bond. Observing: How many covalent bonds are there between the two carbon atoms in acetylene?

Methane  Acetylene  Butadiene  Benzene  Isooctane

Key Questions

- What elements does carbon bond with to make up life’s molecules?
- What are the functions of each of the four groups of macromolecules?

Vocabulary

- monomer
- polymer
- carbohydrate
- monosaccharide
- lipid
- nucleic acid
- nucleotide
- protein
- amino acid

Taking Notes

Compare/Contrast Table  As you read, make a table that compares and contrasts the four groups of organic compounds.

Answers

FIGURE 2–12  three

Teach for Understanding

ENDURING UNDERSTANDING  The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

GUIDING QUESTION  How do organisms use different types of carbon compounds?

EVIDENCE OF UNDERSTANDING  After completing the lesson, give students the following assessment to show they understand the functions of the different types of carbon compounds in organisms. Ask each student to create a four-page brochure, with each page devoted to one of the four major types of carbon compounds in living things. For each type of compound, students should diagram its general structure and describe its functions in organisms.
LESSON 2.3

Connect to Chemistry
After students read about polymerization, tell them that polymerization commonly occurs in one of two ways: addition polymerization or condensation polymerization. Explain that in addition polymerization, monomers join together without any change in their molecules. In condensation polymerization, a small molecule—often a water molecule—is released each time monomers join together. Next, write the chemical formulas for glucose (C₆H₁₂O₆) and sucrose (C₁₂H₂₂O₁₁) on the board. Remind students that glucose is a monosaccharide and sucrose is a disaccharide.

Ask Is carbohydrate polymerization an example of addition or condensation polymerization? (condensation polymerization)
You may wish to draw a sketch of the reaction on the board, as shown below:

![Figure 2–13 Polymerization](image)

Ask Condensation reactions are sometimes known as hydrolysis reactions. Why? (A water molecule is lost. Hydrolysis means loss of water.) Next, show students the opposite of a dehydration reaction, called a hydrolysis reaction:

![Figure 2–14 Carbohydrates](image)

Explain to your students that dehydration and hydrolysis reactions are extremely common in biochemical processes.

DIFFERENTIATED INSTRUCTION

**LPR Less Proficient Readers** Have students read the Build Vocabulary feature on this page. Tell them that a saccharide is a sugar and the prefix di- means “two.” Then, ask them to predict the meanings of the terms monosaccharide, disaccharide, and polysaccharide. (one sugar, two sugars, and many sugars, respectively)

Answers

**FIGURE 2–13** Links are small units that are joined together to form a chain. In a similar way, monomers are small compounds that are joined together to form large compounds called polymers.

**FIGURE 2–14** Carbohydrates Starches form when sugars join together in a long chain. Each time two glucose molecules are joined together, a molecule of water (H₂O) is released when the covalent bond is formed.

**Macromolecules**

What are the functions of each of the four groups of macromolecules?

Many of the organic compounds in living cells are so large that they are known as macromolecules, which means “giant molecules.” Macromolecules are made from thousands or even hundreds of thousands of smaller molecules.

Most macromolecules are formed by a process known as polymerization (pah lyurm ih vay shen), in which large compounds are built by joining smaller ones together. The smaller units, or **monomers**, join together to form **polymers**. The monomers in a polymer may be identical, like the links on a metal watch band; or the monomers may be different, like the beads in a multicolored necklace. **Figure 2–13** illustrates the process of polymerization.

Biochemists sort the macromolecules found in living things into groups based on their chemical composition. The four major groups of macromolecules found in living things are carbohydrates, lipids, nucleic acids, and proteins. As you read about these molecules, compare their structures and functions.

**Carbohydrates** Carbohydrates are compounds made up of carbon, hydrogen, and oxygen atoms, usually in a ratio of 1:2:1. Living things use carbohydrates as their main source of energy. Plants, some animals, and other organisms also use carbohydrates for structural purposes. The breakdown of sugars, such as glucose, supplies immediate energy for cell activities. Many organisms store extra sugar as complex carbohydrates known as starches. As shown in **Figure 2–14**, the monomers in starch polymers are sugar molecules.

- **Simple Sugars** Single sugar molecules are also known as **monosaccharides** (mahn oh sak uh rydz). Besides glucose, monosaccharides include galactose, which is a component of milk, and fructose, which is found in many fruits. Ordinary table sugar, sucrose, consists of glucose and fructose. Sucrose is a disaccharide, a compound made by joining two simple sugars together.

**Biology In-Depth**

**More Functions of Carbohydrates**

In recent years, researchers have found that carbohydrates have more functions in living things than just providing energy and helping to give organisms structure. They have discovered that carbohydrates also play important roles in the interactions of cells within organisms. Simple sugar molecules attached to larger protein molecules appear to act like ID tags on the larger molecules. For example, these “glycoproteins” may allow sperm to recognize egg cells during fertilization and fetuses to avoid detection and attack by the maternal immune system during gestation. The sugar molecules may also help white blood cells identify infected tissues. Errors in the formation of sugar ID molecules have been implicated in some autoimmune disorders.
**Complex Carbohydrates** The large macromolecules formed from monosaccharides are known as polysaccharides. Many animals store excess sugar in a polysaccharide called glycogen, which is sometimes called “animal starch.” When the level of glucose in your blood runs low, glycogen is broken down into glucose, which is then released into the blood. The glycogen stored in your muscles supplies the energy for muscle contraction and, thus, for movement.

Plants use a slightly different polysaccharide, called starch, to store excess sugar. Plants also make another important polysaccharide called cellulose. Tough, flexible cellulose fibers give plants much of their strength and rigidity. Cellulose is the major component of both wood and paper, so you are actually looking at cellulose as you read these words!

**Lipids** Lipids are a large and varied group of biological molecules that are generally not soluble in water.

Lipids are made mostly from carbon and hydrogen atoms. The common categories of lipids are fats, oils, and waxes. Lipids can be used to store energy. Some lipids are important parts of biological membranes and waterproof coverings. Steroids synthesized by the body are lipids as well. Many steroids, such as hormones, serve as chemical messengers.

Many lipids are formed when a glycerol molecule combines with compounds called fatty acids, as shown in Figure 2–15. If each carbon atom in a lipid’s fatty acid chains is joined to another carbon atom by a single bond, the lipid is said to be saturated. The term saturated is used because the fatty acids contain the maximum possible number of hydrogen atoms.

If there is at least one carbon-carbon double bond in a fatty acid, the fatty acid is said to be unsaturated. Lipids whose fatty acids contain more than one double bond are said to be polyunsaturated. If the terms saturated and polyunsaturated seem unfamiliar, you have probably seen them on food package labels. Lipids that contain unsaturated fatty acids, such as olive oil, tend to be liquid at room temperature. Other cooking oils, such as corn oil, sesame oil, canola oil, and peanut oil, contain polyunsaturated lipids.

**In Your Notebook** Compare and contrast saturated and unsaturated fats.

**Figure 2–15** Lipids Lipid molecules are made up of glycerol and fatty acids. Liquid lipids, such as olive oil, contain mainly unsaturated fatty acids.

---

**Check for Understanding**

**QUESTION BOX**

Ask students to write a question they have about carbohydrates or lipids on a scrap of paper. Then, pass an empty shoe box around the room, and have students place their questions in the box. This will give students who are uncomfortable asking questions aloud in class a chance to have their questions answered.

**ADJUST INSTRUCTION**

Review students’ questions, and select the most important or fundamental questions that students have raised. Read the questions aloud in class, and call on volunteers to answer them.

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**Build Reading Skills**

Ask students if they ever heard the expression, “A picture is worth 1000 words.” Tell them that looking at the photographs, diagrams, and graphs in their textbook when they read can help them understand the material. When they read about carbohydrates, have them examine Figure 2–14, and when they read about lipids, have them look at Figure 2–15. The figures will help students understand the structures of the two types of macromolecules. For example, Figure 2–15 will show them the composition of lipids and help them understand how saturated and unsaturated lipids differ. Suggest they check their comprehension by asking themselves: What makes the lipid in Figure 2–15 unsaturated?

**DIFFERENTIATED INSTRUCTION**

**Special Needs** Use Cloze Prompts to help students focus on the most important information about lipids. Have them write the following prompts on a sheet of paper and try to fill in the missing words as they read:

- Lipids are made mostly from carbon and ______. (hydrogen atoms)
- Lipids can be used to store ______. (energy)
- Lipids are part of biological ______. (membranes and waterproof coverings)
- Lipids contain glycerol and ______. (fatty acids)
- Lipids that are liquid at room temperature contain ______ fatty acids. (unsaturated)

**Study Wkbks A/B, Appendix S2, Cloze Prompts.**

**Advanced Students** Have students learn about the roles of saturated and unsaturated lipids in nutrition and health. Then, ask them, to share what they learn in a presentation to the class. In their presentation, they should include recommendations for food choices that have healthy amounts and types of lipids.

**Answers**

**IN YOUR NOTEBOOK** Both types of fats are lipids that form when a glycerol molecule combines with fatty acid compounds. In saturated fats, each carbon atom in the fatty acid chains is joined to another carbon atom by a single bond. In unsaturated fats, at least one carbon atom in the fatty acid chains is joined to another carbon atom by a double bond. At room temperature, saturated fats tend to be solids and unsaturated fats tend to be liquids.
Use Models

Challenge individual students to use materials of their choice to create a three-dimensional model of a nucleic acid or a protein. For example, a student might use interlocking brick construction toys in different colors and shapes to represent nitrogenous bases, phosphate groups, and 5-carbon sugars, and join the bricks together in the correct arrangement to model a nucleic acid. Other materials students might use include modeling clay, toothpicks, and beads. Tell students to make a key for their model showing what each part represents. Have students display their models in the classroom as you work through the lesson.

Differentiated Instruction

ELL Struggling Students Have students work in small groups to create models of a nucleic acid and a protein. Suggest they talk about the structure of each molecule and write down a quick plan for how they will model it before they begin construction.

Focus on ELL: Build Background

ALL SPEAKERS Show students visuals of carbohydrates, lipids, nucleic acids, and proteins. Then, have them apply the Think-Pair-Share strategy. Give students time to think about what they learned from the visuals. Then, pair beginning and intermediate speakers with advanced and advanced high speakers. Have partners discuss the visuals to help them make a list of descriptive terms and examples that are associated with each type of macromolecule. Ask partners to share their lists with the class.

Study Wkbks A/B, Appendix S14, Think-Pair-Share.

Comparing Fatty Acids

The table compares four different fatty acids. Although they all have the same number of carbon atoms, their properties vary.

1. Interpret Data Which of the four fatty acids is saturated? Which are unsaturated?

2. Observe How does melting point change as the number of carbon–carbon double bonds increases?

3. Infer If room temperature is 25°C, which fatty acid is a solid at room temperature? Which is liquid at room temperature?

### Effect of Carbon Bonds on Melting Point

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>Number of Carbons</th>
<th>Number of Double Bonds</th>
<th>Melting Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stearic</td>
<td>18</td>
<td>0</td>
<td>69.6</td>
</tr>
<tr>
<td>Oleic</td>
<td>18</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Linoleic</td>
<td>18</td>
<td>2</td>
<td>−5</td>
</tr>
<tr>
<td>Linolenic</td>
<td>18</td>
<td>3</td>
<td>−11</td>
</tr>
</tbody>
</table>

**FIGURE 2–16 Nucleic Acids**

The monomers that make up a nucleic acid are nucleotides. Each nucleotide has a 5-carbon sugar, a phosphate group, and a nitrogenous base.

**FIGURE 2–17 Amino Acids and Peptide Bonding**

Peptide bonds form between the amino group of one amino acid and the carboxyl group of another amino acid. A molecule of water (H₂O) is released when the bond is formed. Note that it is the variable R group section of the molecule that distinguishes one amino acid from another.

**Nucleic Acids**

Nucleic acids are macromolecules containing hydrogen, oxygen, nitrogen, carbon, and phosphorus. Nucleic acids are polymers assembled from individual monomers known as nucleotides. Nucleotides consist of three parts: a 5-carbon sugar, a phosphate group (−PO₄), and a nitrogenous base, as shown in Figure 2–16. Some nucleotides, including the compound known as adenosine triphosphate (ATP), play important roles in capturing and transferring chemical energy. Individual nucleotides can be joined by covalent bonds to form a polynucleotide, or nucleic acid.

**Protein**

Proteins are macromolecules that contain nitrogen as well as carbon, hydrogen, and oxygen. Proteins are polymers of molecules called amino acids, shown in Figure 2–17. Amino acids are compounds with an amino group (−NH₂) on one end and a carboxyl group (−COOH) on the other end. Covalent bonds called peptide bonds link amino acids together to form a polypeptide. A protein is a functional molecule built from one or more polypeptides. Some proteins control the rate of reactions and regulate cell processes. Others form important cellular structures, while still others transport substances into or out of cells or help to fight disease.

**General Structure of Amino Acids**

- **Amino group**: \( \text{H} - \text{C} - \text{N} \)
- **Carboxyl group**: \( \text{H} - \text{C} - \text{OH} \)

**Formation of Peptide Bond**

\[
\begin{align*}
\text{H} & \quad \text{C} & \quad \text{H} & \quad \text{N} \\
\text{H} & \quad \text{C} & \quad \text{O} & \quad \text{H} \\
\text{H} & \quad \text{C} & \quad \text{O} & \quad \text{H} \\
\text{H} & \quad \text{C} & \quad \text{N} & \quad \text{C} \\
\text{H} & \quad \text{C} & \quad \text{N} & \quad \text{C} \\
\end{align*}
\]

**ANSWERS**

1. Stearic acid is saturated. The other three fatty acids in the table are unsaturated.
2. Melting point decreases as the number of double bonds increases.
3. Stearic acid is a solid at room temperature. The other three fatty acids are liquids at room temperature.
Assess and Remedi ate

EVALUATE UNDERSTANDING

Ask a volunteer to explain what macromolecules are. Ask another student to go to the board and list the four main groups of macromolecules found in organisms. Call on one student after another to describe the structure or identify a function of one of the groups of macromolecules. Then, have students complete the 2.3 Assessment.

REMEDIATION SUGGESTION

For Less Proficient Readers If students have trouble with Question 2c, have them reread the definition of polymer. Then, have them look closely at the structure of lipids in Figure 2–15 and the structure of proteins in Figure 2–18.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.
Chemical Reactions and Enzymes

Getting Started

Objectives
2.4.1 Explain how chemical reactions affect chemical bonds.
2.4.2 Describe how energy changes affect how easily a chemical reaction will occur.
2.4.3 Explain why enzymes are important to living things.

Student Resources
Study Workbooks A and B, 2.4 Worksheets
Spanish Study Workbook, 2.4 Worksheets

ACTIVATE PRIOR KNOWLEDGE

Ask students if they have ever put together a jigsaw puzzle. Call on a volunteer to draw a simple sketch that shows how two adjacent puzzle pieces might look. Ask students how they can tell that the two puzzle pieces fit together. (They have complementary shapes.) Tell them that certain proteins called enzymes fit together with other molecules in a similar way.

Enduring Understanding
The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

Guiding Question
How do chemicals combine and break apart inside living things?

Evidence of Understanding
After completing the lesson, give students the following assessment to show they understand how enzymes work. Ask small groups of students to use various small items (such as different shapes of dry pasta and modeling clay) to create a three-dimensional model of an enzyme-catalyzed reaction. Their model should include symbols for the substrates, enzyme, and products. It should represent each step of the reaction and show how the enzyme is unchanged and ready to catalyze another reaction after it releases the products.

Key Questions
What happens to chemical bonds during chemical reactions?
How do energy changes affect whether a chemical reaction will occur?
What role do enzymes play in living things and what affects their function?

Vocabulary
chemical reaction • reactant • product • activation energy • catalyst • enzyme • substrate

Taking Notes
Concept Map As you read, make a concept map that shows the relationship among the vocabulary terms in this lesson.

FIGURE 2–19 Carbon Dioxide in the Bloodstream
As it enters the blood, carbon dioxide reacts with water to produce carbonic acid (H₂CO₃), which is highly soluble. This reaction enables the blood to carry carbon dioxide to the lungs. In the lungs, the reaction is reversed and produces carbon dioxide gas, which you exhale.

THINK ABOUT IT
Living things, as you have seen, are made up of chemical compounds—some simple and some complex. But chemistry isn’t just what life is made of—chemistry is also what life does. Everything that happens in an organism—its growth, its interaction with the environment, its reproduction, and even its movement—is based on chemical reactions.

Chemical Reactions
A chemical reaction is a process that changes, or transforms, one set of chemicals into another. An important scientific principle is that mass and energy are conserved during chemical transformations. This is also true for chemical reactions that occur in living organisms. Some chemical reactions occur slowly, such as the combination of iron and oxygen to form an iron oxide called rust. Other reactions occur quickly. The elements or compounds that enter into a chemical reaction are known as reactants. The elements or compounds produced by a chemical reaction are known as products. Chemical reactions involve changes in the chemical bonds that join atoms in compounds. An important chemical reaction in your bloodstream that enables carbon dioxide to be removed from the body is shown in Figure 2–19.
Energy in Reactions

**How do energy changes affect whether a chemical reaction will occur?**

Energy is released or absorbed whenever chemical bonds are formed or broken. This means that chemical reactions also involve changes in energy.

**Energy Changes** Some chemical reactions release energy, and other reactions absorb it. Energy changes are one of the most important factors in determining whether a chemical reaction will occur. Chemical reactions that release energy frequently occur on their own, or spontaneously. Chemical reactions that absorb energy will not occur without a source of energy. An example of an energy-releasing reaction is the burning of hydrogen gas, in which hydrogen reacts with oxygen to produce water vapor.

\[ 2H_2 + O_2 \rightarrow 2H_2O \]

The energy is released in the form of heat, and sometimes—when hydrogen gas explodes—light and sound.

The reverse reaction, in which water is changed into hydrogen and oxygen gas, absorbs so much energy that it generally doesn’t occur by itself. In fact, the only practical way to reverse the reaction is to pass an electrical current through water to decompose water into hydrogen gas and oxygen gas. Thus, in one direction the reaction produces energy, and in the other direction the reaction requires energy.

**Energy Sources** In order to stay alive, organisms need to carry out reactions that require energy. Because matter and energy are conserved in chemical reactions, every organism must have a source of energy to carry out chemical reactions. Plants get that energy by trapping and storing the energy from sunlight in energy-rich compounds. Animals get their energy when they consume plants or other animals. Humans release the energy needed to grow tall, to breathe, to think, and even to dream through the chemical reactions that occur when we metabolize, or break down, digested food.

**Activation Energy** Chemical reactions that release energy do not always occur spontaneously. That’s a good thing because if they did, the pages of this book might burst into flames. The cellulose in paper burns in the presence of oxygen and releases heat and light. However, paper burns only if you light it with a match, which supplies enough energy to get the reaction started. Chemists call the energy that is needed to get a reaction started the activation energy. As Figure 2–20 shows, activation energy is involved in chemical reactions regardless of whether the overall chemical reaction releases energy or absorbs energy.

**Energy Sources**

- Energy-absorbing reaction—the energy of the reactants is greater than the energy of the products; Energy-releasing reaction—the energy of the reactants is less than the energy of the products.

**Spontaneous Chemical Reactions** Students may tend to equate “spontaneous” with “fast.” Explain to students that spontaneous reactions do not necessarily occur quickly. A spontaneous reaction proceeds on its own without an added source of energy, but it could take quite a long time. For example, diamonds spontaneously decay into graphite, but this process takes millions of years!
Use Visuals

Discuss the importance of enzymes and the way enzymes work. Ask students how the reaction represented by Figure 2–21 is different with the enzyme than without it. (The activation energy is lower with the enzyme.) Explain how lowering the activation energy speeds up the reaction by allowing many more molecules to react. Have students look at Figure 2–22, and point out the cyclic nature of the diagram.

Ask Why is a cycle diagram appropriate to show how an enzyme works? (The enzyme can be used over and over again, which allows the process to keep repeating.)

DIFERENTIATED INSTRUCTION

Struggling Students Have students make a simplified Cycle Diagram of Figure 2–22 to show the sequence of steps in an enzyme-catalyzed reaction. For each step in the diagram, they should write a sentence describing in their own words what happens in that step.


VISUAL ANALOGY

Discuss Figure 2–23, the lock-and-key analogy, with the class. Have students identify what the lock, key, and keyhole represent in the analogy. (lock—enzyme; key—substrates; keyhole—active site) Tell students that the analogy is a simplified representation of what happens when substrates bind to the active site of an enzyme. For example, rather than being rigid like a keyhole, the active site may actually change shape when substrates bind to it.

With the Visual Analogy: Lock and Key, students can interact with an animation to learn more about enzymes and substrates.

Answers

FIGURE 2–22 The carbonic anhydrase is free to catalyze another reaction.

Enzymes

The role of enzymes in living things and what affects their function?

Some chemical reactions that make life possible are too slow or have activation energies that are too high to make them practical for living tissue. These chemical reactions are made possible by a process that would make any chemist proud—cells make catalysts. A catalyst is a substance that speeds up the rate of a chemical reaction. Catalysts work by lowering a reaction’s activation energy.

Nature’s Catalysts Enzymes are proteins that act as biological catalysts. Enzymes speed up chemical reactions that take place in cells. Like other catalysts, enzymes act by lowering the activation energies, as illustrated by the graph in Figure 2–21. Lowering the activation energy has a dramatic effect on how quickly the reaction is completed. How big an effect does it have? Consider the reaction in which carbon dioxide combines with water to produce carbonic acid.

CO₂ + H₂O → H₂CO₃

Left to itself, this reaction is so slow that carbon dioxide might build up in the body faster than the bloodstream could remove it. Your bloodstream contains an enzyme called carbonic anhydrase that speeds up the reaction by a factor of 10 million. With carbonic anhydrase on the job, the reaction takes place immediately and carbon dioxide is removed from the blood quickly.

Enzymes are very specific, generally catalyzing only one chemical reaction. For this reason, part of an enzyme’s name is usually derived from the reaction it catalyzes. Carbonic anhydrase gets its name because it also catalyzes the reverse reaction that removes water from carbonic acid.

The Enzyme-Substrate Complex How do enzymes do their jobs? For a chemical reaction to take place, the reactants must collide with enough energy so that existing bonds will be broken and new bonds will be formed. If the reactants do not have enough energy, they will be unchanged after the collision.

Enzymes provide a site where reactants can be brought together to react. Such a site reduces the energy needed for reaction. The reactants of enzyme-catalyzed reactions are known as substrates. Figure 2–22 provides an example of an enzyme-catalyzed reaction.
The substrates bind to a site on the enzyme called the active site. The active site and the substrates have complementary shapes. The fit is so precise that the active site and substrates are often compared to a lock and key, as shown in Figure 2–23.

**Regulation of Enzyme Activity** Enzymes play essential roles in controlling chemical pathways, making materials that cells need, releasing energy, and transferring information. Because they are catalysts for reactions, enzymes can be affected by any variable that influences a chemical reaction. Temperature, pH, and regulatory molecules can affect the activity of enzymes.

Many enzymes are affected by changes in temperature. Not surprisingly, those enzymes produced by human cells generally work best at temperatures close to 37°C, the normal temperature of the human body. Enzymes work best at certain ionic conditions and pH values. For example, the stomach enzyme pepsin, which begins protein digestion, works best under acidic conditions. In addition, the activities of most enzymes are regulated by molecules that carry chemical signals within cells, switching enzymes “on” or “off” as needed.

**Assess and RemEDIATE**

**EVALUATE UNDERSTANDING**

Ask students to write a paragraph explaining how chemical reactions occur in living things. Then, have them complete the 2.4 Assessment.

**REMEDICATION SUGGESTION**

**Special Needs** If students have trouble with Question 3c, have them reexamine Figure 2–23. Explain that a change in the shape of an enzyme can be compared to changing the shape of the lock’s keyhole. When an enzyme changes shape, it may not fit with its substrate any more.

**Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.**

**Assessment Answers**

1a. The bonds change—often they are formed or broken.

1b. because new chemicals are not formed

2a. the energy that is needed to get a reaction started

2b. A reaction that occurs spontaneously releases energy. A reaction that does not occur spontaneously absorbs energy.

3a. proteins that act as biological catalysts

3b. Enzymes provide a site where reactants, called substrates, can be brought together to react. The substrates bind to a site on the enzyme called the active site, forming an enzyme-substrate complex. This reduces the activation energy needed for the reaction.

3c. If a change in pH changes the shape of an enzyme, it might result in the enzyme and substrates no longer fitting together properly. As a result, the enzyme would no longer be able to speed up the chemical reaction.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Temperature Affects Enzymes described in Lab Manual A.

Struggling Students  A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Remind students to wear goggles, gloves, and aprons during the lab, because hydrogen peroxide irritates skin and bleaches clothing. Tell them that the puréed liver is raw and may contain bacteria, so it is very important for them to wash their hands after they finish the lab.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 46.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP  I, II, III
CONTENT  B.3, C.1.d
INQUIRY  A.1.b

Pre-Lab Answers

BACKGROUND QUESTIONS
a. Reactions in cells are often too slow or require an activation energy that is not practical for living tissue. Enzymes lower the activation energy of reactions.
b. pH, temperature, and regulatory molecules
c. Sample answer: The frying pan is like an enzyme. It provides a location where the eggs can be cooked. The control knob allows the user to control the temperature of the frying pan, which affects how fast the eggs cook.

PRE-LAB QUESTIONS
1. I will observe bubbles of oxygen on the surface of the liver. The filter paper disk will rise to the top of the purée.
2. temperature; reaction time
3. Oxygen produced in the reaction causes the disk to float. The rate of the reaction that produces the oxygen depends on the activity of the enzyme. The more active the enzyme, the faster the oxygen is produced, and the quicker the disk will rise.
2 Study Guide

Big Idea  Matter and Energy

Chemical bonds join together the molecules and compounds of life. Water and carbon compounds play essential roles in organisms, which carry out chemical reactions in their daily life processes.

2.1 The Nature of Matter

- The subatomic particles that make up atoms are protons, neutrons, and electrons.
- All isotopes of an element have the same chemical properties, because they have the same number of electrons.
- The physical and chemical properties of a compound are usually very different from those of the elements from which it is formed.
- The main types of chemical bonds are ionic bonds and covalent bonds.

atom (34)    ionic bond (37)
nucleus (34)  ion (37)
electron (34) covalent bond (37)
element (35)  molecule (37)
isotope (35)  van der Waals forces (38)
compound (36)

2.2 Properties of Water

Water is a polar molecule. Therefore, it is able to form multiple hydrogen bonds, which account for many of its special properties.
- Water’s polarity gives it the ability to dissolve both ionic compounds and other polar molecules.
- Buffers play an important role in maintaining homeostasis in organisms.

hydrogen bond [41] solution [42] pH scale [43]
cohesion [41] solute [42] acid [44]
adhesion [41] solvent [42] base [44]
mixture [42] suspension [42] buffer [44]

2.3 Carbon Compounds

Carbon can bond with many elements, including hydrogen, oxygen, phosphorus, sulfur, and nitrogen to form the molecules of life.

UBD Performance Tasks

SUMMATIVE TASK  Have students work in pairs to create a simple storybook for younger children on the chemistry of living things. In addition to introducing basic concepts such as atoms, molecules, and chemical reactions, students should describe the structure and functions of the four groups of carbon compounds in living things.

TRANSFER TASK  Introduce inherited defects in enzymes that are needed for metabolism, or the chemical reactions inside cells. Explain that inherited defects of metabolism can cause serious health problems. Have students work in small groups to identify a particular metabolism defect, such as phenylketonuria (PKU), and create a presentation about it. In their presentation, students should identify the enzyme that is defective, its normal role in metabolism, and how a defect in the enzyme affects metabolism and health.

Study Online

REVIEW AND ASSESSMENT RESOURCES

Editable Worksheets  Pages of Study Workbooks A and B, Lab Manuals A and B, and the Assessment Resources Book are available online. These documents can be easily edited using a word-processing program.

Lesson Overview  Have students reread the Lesson Overviews to help them study Chapter 2 concepts.

Vocabulary Review  The Flash Cards and Match It provide an interactive way to review chapter vocabulary.

Chapter Assessment  Have students take an online version of the Chapter 2 Assessment.

Standardized Test Prep  Students can take an online version of the Standardized Test Prep. You will receive their scores along with ideas for remediation.

Diagnostic and Benchmark Tests  Use these tests to monitor your students’ progress and supply remediation.

Answers

THINK VISUALLY

Student tables should show that

- carbohydrates consist of simple sugars called monosaccharides or chains of sugars called polysaccharides; they provide energy or structure.
- lipids consist of glycerol and fatty acids; they store energy or are part of membranes and waterproof coverings.
- nucleic acids consist of chains of nucleotides; they store and transmit genetic information.
- proteins consist of chains of amino acids; they control the rate of reactions, regulate cell processes, form cell structures, transport substances into or out of cells, or help fight disease.
Lesson 2.1

UNDERSTAND KEY CONCEPTS

1. c  2. d  3. b
4. Elements are composed of atoms. Compounds are composed of atoms of two or more elements combined in definite proportions.
5. A radioactive isotope is an isotope with an unstable nucleus that breaks down at a constant rate over time. Scientific uses of radioactive isotopes include determining the age of rocks, treating cancer, killing bacteria in food, and tracing the movements of substances within organisms.
6. Atoms in a compound are held together by chemical bonds.
7. Two electrons are shared in a single covalent bond, four in a double bond, and six in a triple bond.

THINK CRITICALLY

8. The diagram should show that hydrogen and chlorine form a covalent bond. Students can use the chlorine atom in Figure 2–4 as a starting point and pair one of the seven electrons in its outer level with hydrogen’s single electron.
9. 0.1 nm; If 100 million atoms lined up are 1 cm in length, then the diameter of one atom equals 1 cm divided by 100,000,000. This yields 1 × 10⁻⁸ cm, or 1 × 10⁻¹⁰ m, which equals 0.1 nm.

Lesson 2.2

UNDERSTAND KEY CONCEPTS

10. b  11. b  12. c
13. Cohesion is an attraction between molecules of the same substance. An example is water molecules drawing together, forming beads on a smooth surface. Adhesion is an attraction between molecules of different substances. An example is capillary action.
14. A solution is a mixture in which one substance is dissolved in another. The solute is the substance that is dissolved. The solvent is the substance in which the solute is dissolved.
15. An acid is a compound that forms hydrogen ions in solution. Acidic solutions have pH values less than 7. A base is a compound that forms hydroxide ions in solution. Basic solutions have pH values greater than 7.

THINK CRITICALLY

16. The mixture could be separated by adding water. The sodium chloride would dissolve in the water, but the silica would not. The salt could then be retrieved by filtering the silica out of the mixture and evaporating the water.
17. Students should infer that magnesium hydroxide is a base. The base reacts with the acid in the stomach and forms a less acidic product.

Lesson 2.3

UNDERSTAND KEY CONCEPTS

18. c  19. c
20. Polymers are large macromolecules made up of smaller molecules called monomers. For example, monomers called monosaccharides join together to form polymers called polysaccharides.
21. Proteins control the rate of chemical reactions, regulate cell processes, form important cellular structures, transport substances into or out of cells, and help fight disease.
22. a 5-carbon sugar, a phosphate group, and a nitrogenous base

THINK CRITICALLY
23. Sample answer: Students might suggest trying to dissolve the solid in water, because lipids are generally not water soluble. They also might suggest warming the solid to see if it would soften, because solid lipids tend to soften when heated.

24. “Carbo” indicates that carbon is present; “hydrate” suggests oxygen and hydrogen are present.

Lesson 2.4

UNDERSTAND KEY CONCEPTS
25. a 26. d
27. A chemical reaction can either release or absorb energy.
28. An enzyme is a biological catalyst.
29. Factors that may influence enzyme activity include pH, temperature, and regulatory molecules that switch enzymes “on” or “off” as needed.
Connecting Concepts

USE SCIENCE GRAPHICS

33. **Interpret Graphs** At which temperature was the greatest amount of product formed?

34. **Draw Conclusions** Describe the results of each reaction. How can you explain these results?

35. **Predict** A student performs the same chemical reaction at 30°C. Approximately how much product can she expect to obtain?

WRITE ABOUT SCIENCE

36. **Explanation** Write a paragraph that includes the following:

(a) a description of the four major classes of organic compounds found in living things, and

(b) a description of how these organic compounds are used by the human body.

37. **Assess the Purpose** What properties of carbon allow it to play such a major role in the chemistry of living things?

38. **Interpret Graphs** At what time of day is the pond most acidic?

   a. between noon and 6:00 P.M.
   b. at noon
   c. between midnight and 6:00 A.M.
   d. at 6:00 P.M.

39. **Form a Hypothesis** Which of the following is the most reasonable hypothesis based on the results obtained?

   a. Pond water maintains constant pH throughout the day.
   b. pH rises with increasing daylight and falls with decreasing daylight.
   c. Living things cannot survive in this pond because enzymes will be destroyed.
   d. pH is higher at night than during the day.
Standardized Test Prep

Multiple Choice
1. The elements or compounds that enter into a chemical reaction are called
2. Chemical bonds that involve the total transfer of electrons from one atom or group of atoms to another are called
3. Which of the following is NOT an organic molecule found in living organisms?
   A protein   B nucleic acid   C sodium chloride   D lipid
4. Which combination of particle and charge is correct?
   A proton: positively charged
   B electron: positively charged
   C neutron: negatively charged
   D electron: no charge
5. In which of the following ways do isotopes of the same element differ?
   A in number of neutrons only
   B in number of protons only
   C in numbers of neutrons and protons
   D in number of neutrons and in mass
6. Which of the following molecules is made up of glycerol and fatty acids?
   A sugars   B starches
   C lipids   D nucleic acids
7. Nucleotides consist of a phosphate group, a nitrogenous base, and a

Questions 8–9
The enzyme catalase speeds up the chemical reaction that changes hydrogen peroxide into oxygen and water. The amount of oxygen given off is an indication of the rate of the reaction.

8. Based on the graph, what can you conclude about the relationship between enzyme concentration and reaction rate?
   A Reaction rate decreases with increasing enzyme concentration.
   B Reaction rate increases with decreasing enzyme concentration.
   C Reaction rate increases with increasing enzyme concentration.
   D The variables are indirectly proportional.
9. Which concentration of catalase will produce the fastest reaction rate?
   A 5%
   B 10%
   C 15%
   D 20%

Open-Ended Response
10. List some of the properties of water that make it such a unique substance.

Answers
1. D
2. B
3. C
4. A
5. D
6. C
7. C
8. C
9. D
10. Sample answer: Properties of water that make it such a unique substance include the polarity of its molecules, which allows them to form hydrogen bonds with each other. Because of these properties, water exhibits cohesion, adhesion, high heat capacity, and the ability to dissolve many substances.

If You Have Trouble With . . .

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>7</th>
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<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>See Lesson</td>
<td>2.4</td>
<td>2.1</td>
<td>2.3</td>
<td>2.1</td>
<td>2.1</td>
<td>2.3</td>
<td>2.3</td>
<td>2.4</td>
<td>2.4</td>
<td>2.2</td>
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</table>

Test-Taking Tip

USE TIME WISELY
Advise students to skip to the next question if they get stuck on a difficult one. Suggest they respond to the questions they can answer easily first, and then go back to questions they have trouble answering. For these difficult ones, make sure they take the time to reread the entire question before attempting to answer it.
Plan Ahead

After students have read what their task will be in the Unit 1 Project, suggest they review how to design a controlled experiment and what independent and dependent variables are. Also, make sure students understand acids, bases, and pH. If students haven’t already tested pH during a previous activity, consider demonstrating how pH paper is used. You may want to direct students to selected experiments in a lab manual to help familiarize them with experimental procedures.

Monitor the Project

Suggest students begin by writing a hypothesis for the first of their three experiments. Briefly check that each student’s hypothesis can be tested with a controlled experiment. Then, as they design their experiments, ask individual students questions that will help them identify variables, write a procedure, and think of ways to collect and record data to test the hypothesis.

Ask What are the independent and dependent variables in your experiment?

Ask How will data be collected in this experiment to show whether the medication actually neutralizes stomach acid?

Project Assessment

Make sure students use the rubric and reflection questions to assess their work. Then, use the rubric to assign a final score. Note that it is important to value the creativity of students’ work as well as the content when you score their projects. If desired, talk with students about any differences between their self-assessment scores and your assigned score.

Unit Project

Design the Experiment

Did you ever wonder how a medication goes from the lab to your local drug store shelf? A lot of research and experimentation by scientists goes into testing a new medication to make sure it is safe and effective. Imagine you are a scientist working for a pharmaceutical company. Your current project is to test a new medication for heartburn. Heartburn is a painful condition in which acid inside the stomach backs up into the esophagus—the connection between your throat and stomach. This new medication helps neutralize stomach acid to prevent irritation.

Your Task  Design three possible experiments to test the safety and effectiveness of the new heartburn medication. Before you begin, think about how you will know if the medication actually neutralizes stomach acid. Once you’ve written your procedures, you will propose the experiments to your company’s Executive Board for Research and Development.

Assessment Rubric

<table>
<thead>
<tr>
<th>Score</th>
<th>Scientific Content</th>
<th>Quality of Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Correctly and extensively applies knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.</td>
<td>Experimental designs are clever and effectively test the hypotheses. Experimental conditions are carefully controlled and variables are correctly identified.</td>
</tr>
<tr>
<td>3</td>
<td>Applies relevant knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.</td>
<td>Experimental designs are logical and test the hypotheses. Experimental conditions are controlled and variables are correctly identified.</td>
</tr>
<tr>
<td>2</td>
<td>Applies relevant knowledge and understanding of unit concepts (i.e., pH scale) incompletely to experimental designs and predictions.</td>
<td>Experimental designs need some revisions—some parts are unclear or do not fully test the hypotheses. Variables and controls need corrections.</td>
</tr>
<tr>
<td>1</td>
<td>Does not correctly apply knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.</td>
<td>Experimental designs are unclear and do not test the hypotheses. Variables and controls listed are incorrect or absent.</td>
</tr>
</tbody>
</table>

Reflection Questions

1. Score your experimental designs using the rubric below. What score did you give yourself?
2. What did you do well in this project?
3. What about your designs needs improvement?
4. Are there any ethical dilemmas related to your experiments? Explain.

21st Century Skills

To be successful in the 21st century, students need skills and learning experiences that extend beyond subject area mastery. The Unit 1 Project helps students build the following 21st Century Skills: Critical Thinking and Systems Thinking; Problem Identification, Formulation, and Solution; Self-Direction; and Accountability and Adaptability.

FOCUS ON COMMUNICATION  Extend this Unit Project by having small groups of students design and create a magazine advertisement for a hypothetical heartburn medication. Suggest that the advertisement not only extol the virtues of the medication but also teach the consumer about heartburn medications by briefly describing an experiment that supports the medication’s effectiveness. Have groups present their ads to the class.

For more practice building 21st Century Skills, see The Chapter Mystery pages in Study Workbook A.
Dear Colleague,

Ever since I began helping my dad in the garden as a kid, I’ve loved plants. So, when my indoor jungle was first invaded by aphids, spider mites, and mealybugs a few years ago, I had a problem. It was too cold to take plants outside to hose them off. But, I wasn’t comfortable using insecticides indoors, with my son and our dog running around. On a hunch, I searched the Web for “beneficial insects” and found several sites selling species that prey on plant-eating pests. The best sources supplied information on preferred foods and environmental requirements of each predatory species, so I could select the right ones for my conditions. Soon, my own little Integrated Pest Management system included ladybugs, lacewings, predatory mites, and a beetle named Cryptolaemus. Those “good bugs” cost a little more than pesticides. But, I could rest easy, knowing that I could keep herbivore populations under control without exposing my son to potentially harmful chemicals.

This wasn’t rocket science. All forms of life on Earth are involved in interactions with one another and with their environment. Natural populations of insects and plants, predators and prey, parasites and hosts, grow and reproduce. They pass through cycles of increase and decrease, rarely going extinct, yet never taking over the planet, either.

Unfortunately, many Americans don’t think about food chains or nutrient cycles except during food shortages, droughts, or floods. This level of ecological illiteracy is dangerous, because our species is Earth’s most powerful force for change. Human activity now affects not only fish populations in the open ocean, but also vital life-support systems such as the ozone layer and the global greenhouse. I hope this unit helps inspire you to teach your students that human society is part of the biosphere; that biological diversity is a treasure; that clean air, water, and soil are invaluable resources; and that all life is connected. If your students learn these lessons, they and their descendants will enjoy a happier and healthier future.
Connect to the Big Idea

The Great White Egret shown in this picture is just one of the many living things found in the Florida Everglades. Ask students to identify some of the other living and nonliving parts of the Great White Egret’s environment. (Sample answers: living: fish, plants; nonliving: water, air) Have students predict what might happen to the Great White Egret if one of these living or nonliving parts of its environment suddenly vanished. (Sample answer: The Great White Egret might not find the resources it needs to survive.) Ask them to anticipate the answer to the question, How do Earth’s living and nonliving parts interact and affect the survival of organisms?

Have students read over the Chapter Mystery. Tell them that the focus of the Chapter Mystery is the interactions that occur among the living and nonliving parts of an ecosystem. Ask students to describe any predictions they might have about the Chapter Mystery’s solution. After they have completed the chapter, have them compare their predictions to the Chapter Mystery’s solution.

Have students preview the chapter vocabulary terms using the Flash Cards.

CHAPTER 3

3 The Biosphere

Matter and Energy, Interdependence in Nature

Q: How do Earth’s living and nonliving parts interact and affect the survival of organisms?

Great White Egret among some plants in the Florida Everglades

Understanding by Design

Chapter 3 describes the biosphere and how its living and nonliving parts interact. The graphic organizer at the right shows how these topics connect to the Big Idea, Essential Question, and Guiding Questions. This framework helps students reach the Enduring Understanding of how the existence of life on Earth depends on interactions among organisms and between organisms and their environment.

PERFORMANCE GOALS

Students will demonstrate mastery of chapter content through their responses to lesson assessments and their performance of data analysis activities and labs. They will synthesize chapter content while planning a museum display on the movement of matter and energy in ecosystems and while writing a short story written from the point of view of a producer.
CHANGES IN THE BAY

Marine life in Rhode Island’s Narragansett Bay is changing. One clue to those changes comes from fishing boat captains who boast about catching bluefish in November—a month after those fish used to head south for winter. Catches of winter flounder, however, are not as plentiful as they once were. These changes in fish populations coincide with the disappearance of the annual spring increase in plant and animal growth. Researchers working in the bay, meanwhile, report puzzling changes in the activities of bacteria living in mud on the bay floor. What’s going on?

Farms, towns, and cities surround the bay, but direct human influence on the bay has not changed much lately. So why are there so many changes to the bay’s plant and animal populations? Could these changes be related to mud-dwelling bacteria? As you read the chapter, look for clues to help you understand the interactions of plants, animals, and bacteria in Narragansett Bay. Then, solve the mystery.

Never Stop Exploring Your World.
Finding out about Narragansett Bay is only the beginning. Take a video field trip with the eogeeks of Untamed Science as they unravel the relationships in a food web.

Chapter 3 EQ:
How do living and nonliving parts of the Earth interact and affect the survival of organisms?

3.1 GQ: How do we study life?
3.2 GQ: How do different organisms get the energy they need to survive?
3.3 GQ: How does energy move through an ecosystem?
3.4 GQ: Why is the cycling of matter important to life on Earth?

What’s Online

INSIDE:
• 3.1 What Is Ecology?
• 3.2 Energy, Producers, and Consumers
• 3.3 Energy Flow in Ecosystems
• 3.4 Cycles of Matter

What's Online
Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
Students investigate changes in Narragansett Bay to learn more about the interactions of the living and nonliving parts of the ecosystem.

UNTAMED SCIENCE VIDEO
What a tangled web nature weaves! Follow the eogeeks of Untamed Science as they unravel the relationships in a food web.

ART IN MOTION
Students can zoom in or out to see the levels of organization of living things on Earth.

DATA ANALYSIS
Students simulate a classic ecological data collection method to learn how data are used to monitor a site.

TUTOR TUBE
This online tutorial clarifies producers and consumers and the flow of matter and energy between them.

ART REVIEW
Students can drag and drop labels to reinforce the roles of producers and consumers.

VISUAL ANALOGY
Students compare the reuse of building materials to the recycling of nutrients.

INTERACTIVE ART
This animation lets students interact with the water cycle.

VISUAL ANALOGY
Students can trace the movement of nutrients through the environment.
Getting Started

Objectives
3.1.1 Describe the study of ecology.
3.1.2 Explain how biotic and abiotic factors influence an ecosystem.
3.1.3 Describe the methods used to study ecology.

Student Resources
Study Workbooks A and B, 3.1 Worksheets
Spanish Study Workbook, 3.1 Worksheets
Lab Manual B, 3.1 Hands-On Activity Worksheet

Build Background
Have students identify living and nonliving things in the classroom and record their responses in two bulleted lists on the board. Explain that the classroom is similar to an ecosystem in that it has interacting living and nonliving parts.

What Is Ecology?

THINK ABOUT IT Lewis Thomas, a twentieth-century science writer, was sufficiently inspired by astronauts’ photographs of Earth to write: “Viewed from the distance of the moon, the astonishing thing about the earth . . . is that it is alive.” Sounds good. But what does it mean? Was Thomas reacting to how green Earth is? Was he talking about how you can see moving clouds from space? How is Earth, in a scientific sense, a “living planet”? And how do we study it?

Studying Our Living Planet

What is ecology?
When biologists want to talk about life on a global scale, they use the term biosphere. The biosphere consists of all life on Earth and all parts of the Earth in which life exists, including land, water, and the atmosphere. The biosphere contains every organism, from bacteria living underground to giant trees in rain forests, whales in polar seas, mold spores drifting through the air—and, of course, humans. The biosphere extends from about 8 kilometers above Earth’s surface to as far as 11 kilometers below the surface of the ocean.
The Science of Ecology  Organisms in the biosphere interact with each other and with their surroundings, or environment. The study of these interactions is called ecology. Ecology is the scientific study of interactions among organisms and between organisms and their physical environment. The root of the word ecology is the Greek word oikos, which means “house.” So, ecology is the study of nature’s “houses” and the organisms that live in those houses.

Interactions within the biosphere produce a web of interdependence between organisms and the environments in which they live. Organisms respond to their environments and can also change their environments, producing an ever-changing, or dynamic, biosphere.

Ecology and Economics  The Greek word oikos is also the root of the word economics. Economics is concerned with human “houses” and human interactions based on money or trade. Interactions among nature’s “houses” are based on energy and nutrients. As their common root implies, human economics and ecology are linked. Humans live within the biosphere and depend on ecological processes to provide such essentials as food and drinkable water that can be bought and sold or traded.

Levels of Organization  Ecologists ask many questions about organisms and their environments. Some ecologists focus on the ecology of individual organisms. Others try to understand how interactions among organisms (including humans) influence our global environment. Ecological studies may focus on levels of organization that include those shown in Figure 3–1.

In Your Notebook  Draw a circle and label it “Me.” Then, draw five concentric circles and label each of them with the appropriate level of organization. Describe your population, community, etc.

BUILD Vocabulary

PREFIXES  The prefix inter- means “between or among.” Interdependence is a noun that means “dependence between or among individuals or things.” The physical environment and organisms are considered interdependent because changes in one cause changes in the other.

Interdependence

FIGURE 3–1 Levels of Organization  The kinds of questions that ecologists may ask about the living environment can vary, depending on the level at which the ecologist works. What is the difference between a population and a community?

Levels of Organization: Population, Community, Ecosystem, Biome, and Biosphere

How Science Works

SUSTAINABLE DEVELOPMENT

The student text points out the relationship between the terms ecology and economics. The concept of sustainable development clearly demonstrates the link between these two areas of study. Sustainable development is typically described as development that meets the needs of the current generation while also considering the needs of future generations. Ideals of sustainable development include goals related to ecology, such as the preservation of ecosystems and natural resources, and goals related to economics, such as improved quality of life for individuals in developing areas. The Millennium Development Goals, established by the United Nations, embrace the ideas of sustainable development by including goals such as ending poverty and hunger and sustaining the environment.

Teach

Use Visuals

Use Figure 3–1 to help students understand how ecologists divide the biosphere into levels. The kinds of questions that ecologists may ask about the living environment can vary depending on the level at which they work. Be sure to discuss all the levels of organization shown in the figure.

Ask  What is an example of a question an ecologist studying ecosystems may ask? (Sample answer: What is the relationship between rainfall and amphibian diversity in an ecosystem?)

Ask  Which levels of organization include nonliving things? (ecosystem, biome, biosphere)

DIFFERENTIATED INSTRUCTION

ELL  English Language Learners  As students read about the root of the word ecology (oikos means “house”), explain that the suffix -logy means “study of.” Have students identify other words that contain this suffix. Ask them to predict the meanings of the words they identify.

LPR  Less Proficient Readers  Have students examine the photographs that make up Figure 3–1. For each photo, have a volunteer describe the image using his or her own words. Then, read the label aloud to students. As you move from one photo to the next, point out the relationships between the photos. For example, tell students that the individual organism in the first photo is a member of a population, shown in the second photo.

Answers

FIGURE 3–1 A population is made up of individuals of one species living in the same area. A community includes a variety of species in a particular location.

IN YOUR NOTEBOOK  Students’ diagrams should include a series of concentric circles with the following labels, starting in the middle circle: Me, Population, Community, Ecosystem, Biome, and Biosphere. Each circle should contain a description along with the appropriate label.
Biotic Factors Environment

Like all ecosystems, this pond is affected by a combination of biotic and abiotic factors. Some environmental factors, such as the "muck" around the edges of the pond, are a mix of biotic and abiotic components. Biotic and abiotic factors are dynamic, meaning that they constantly affect each other.

Classify What biotic factors are visible in this ecosystem?

Biocenoses and Biological Factors

Ecologists use the word environment to refer to all conditions, or factors, surrounding an organism. Environmental conditions include biotic factors and abiotic factors, as shown in Figure 3–2.

What are biotic and abiotic factors?

Biotic Factors The biological influences on organisms are called biotic factors. A biotic factor is any living part of the environment with which an organism might interact, including animals, plants, mushrooms, and bacteria. Biotic factors relating to a bullfrog, for example, might include algae it eats as a tadpole, insects it eats as an adult, herons that eat bullfrogs, and other species that compete with bullfrogs for food or space.

Abiotic Factors Physical components of an ecosystem are called abiotic factors. An abiotic factor is any nonliving part of the environment, such as sunlight, heat, precipitation, humidity, wind or water currents, soil type, and so on. For example, a bullfrog could be affected by abiotic factors such as water availability, temperature, and humidity.
Biotic and Abiotic Factors Together

The difference between biotic and abiotic factors may seem to be clear and simple. But if you think carefully, you will realize that many physical factors can be strongly influenced by the activities of organisms. Bullfrogs hang out, for example, in soft “muck” along the shores of ponds. You might think that this muck is strictly part of the physical environment, because it contains nonliving particles of sand and mud. But typical pond muck also contains leaf mold and other decomposing plant material produced by trees and other plants around the pond. That material is decomposing because it serves as “food” for bacteria and fungi that live in the muck.

Taking a slightly wider view, the “abiotic” conditions around that mucky shoreline are strongly influenced by living organisms. A leafy canopy of trees and shrubs often shade the pond’s shoreline from direct sun and protect it from strong winds. In this way, organisms living around the pond strongly affect the amount of sunlight the shoreline receives and the range of temperatures it experiences. A forest around a pond also affects the humidity of air close to the pond. Even certain chemical conditions in the soil around the pond are affected by living organisms. If most trees nearby are pines, their decomposing needles make the soil acidic. If the trees nearby are oaks, the soil will be more alkaline. This kind of dynamic mix of biotic and abiotic factors shapes every environment.

In Your Notebook

In your own words, explain the difference between biotic and abiotic factors. Give three examples of each.

Quick Lab

How Do Abiotic Factors Affect Different Plant Species?

1. Gather four paper cups. Use a pencil to punch three holes in the bottom of each cup. Fill two cups with equal amounts of sand and two cups with the same amount of potting soil. CAUTION: Wash your hands well with soap and warm water after handling soil or plants.
2. Plant five rice seeds in one sand-filled cup and five rice seeds in one soil-filled cup. Plant five rye seeds in each of the other two cups. Label each cup with the type of seeds and soil it contains.
3. Place all the cups in a warm, sunny location. Each day for two weeks, water the cups equally and record your observations of any plant growth.

Analyze and Conclude

1. Analyze Data
   - In which medium did the rice grow better—sand or soil? Which was the better medium for the growth of rye?
2. Infer
   - Soil retains more water than sand does, providing a moister environment. What can you infer from your observations about the kind of environment that favors the growth of rice? What kind of environment favors the growth of rye?
3. Draw Conclusions
   - Which would compete more successfully in a dry environment—rice or rye? Which would be more successful in a moist environment?

Connect to Language Arts

Provide students with this more complete version of the Lewis Thomas quote from the Think About It paragraph at the beginning of the lesson: “Viewed from the distance of the moon, the astonishing thing about the earth, catching the breath, is that it is alive. . . . Aloft, floating free beneath the moist, gleaming membrane of the bright blue sky, is the rising earth, the only exuberant thing in this part of the cosmos.”

Ask
- What abiotic factors does Thomas mention in this quote? (breath, moisture, sky)
- How does this quote show the interdependence of abiotic and biotic factors? (Sample answer: Although Lewis Thomas mentions only abiotic elements, he describes the Earth as living. Living systems contain abiotic and biotic components.)

Differentiated Instruction

Special Needs

The Lewis Thomas quote uses visual imagery to describe some of Earth’s abiotic factors. Ask students to supply other sensory descriptions of abiotic factors, such as the sound of wind or the smell of salt water at the seashore. Further, have students list biotic factors associated with the abiotic factors they have described.

Students should identify three abiotic factors in Narragansett Bay, such as water temperature, levels of nutrients, and water currents. Students can go online to Biology.com to gather their evidence.

Biology.com

Students simulate ecological data collection in Data Analysis: Counting on Nature.

Answers

In Your Notebook

Students should describe biotic factors as living and abiotic factors as nonliving. Biotic factors include plants, animals, bacteria, and fungi. Abiotic factors include sunlight, air temperature, and precipitation.
Assess and Remediate

EVALUATE UNDERSTANDING

Have students work in groups of four. Ask one group member to name an individual organism. Then, have a second group member identify a population in which that organism belongs. The next student should then describe a community in which the population belongs. Finally, the fourth group member should describe an ecosystem in which the community is found. Then, have students complete the 3.1 Assessment.

REMEDIATION SUGGESTION

ELL English Language Learners If your students have trouble with Question 1b, have them review the Build Vocabulary feature on the word interdependence. Then, have them use the word in a sentence to reinforce its meaning.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. individual organism, population, community, ecosystem, biome, biosphere

1b. Sample answer: My dance class and my health are interdependent; I need a healthy body to dance and dancing helps me maintain a healthy body.

2a. abiotic

2b. Biotic and abiotic factors are related in that both are parts of ecosystems. Biotic factors are living, abiotic factors are nonliving.

3a. The three methods of ecological research are observing, experimenting, and modeling. This ecologist is measuring a giant Rafflesia flower in Borneo.

3b. Sample answer: Global warming is an ecological problem that could be studied by modeling more easily than by observation or experimentation, because it occurs over a large area and a long period of time.

4. Answers will vary. Most students will choose experimenting, which would involve testing a hypothesis about whether the water is safe to drink. Some students might choose modeling, which would involve using a model to investigate whether pollutants or organisms could enter the water.

Ecological Methods

What methods are used in ecological studies?

Some ecologists, like the one in Figure 3–3, use measuring tools to observe changes in plant and wildlife communities. Others use DNA studies to identify bacteria in marsh mud. Still others use data gathered by satellites to track ocean surface temperatures. Regardless of their tools, modern ecologists use three methods in their work: observation, experimentation, and modeling. Each of these approaches relies on scientific methodology to guide inquiry.

Observation Observation is often the first step in asking ecological questions. Some observations are simple: Which species live here? How many individuals of each species are there? Other observations are more complex: How does an animal protect its young from predators? These types of questions may form the first step in designing experiments and models.

Experimentation Experiments can be used to test hypotheses. An ecologist may, for example, set up an artificial environment in a laboratory or greenhouse to see how growing plants react to different conditions of temperature, lighting, or carbon dioxide concentration. Other experiments carefully alter conditions in selected parts of natural ecosystems.

Modeling Many ecological events, such as effects of global warming on ecosystems, occur over such long periods of time or over such large distances that they are difficult to study directly. Ecologists make models to help them understand these phenomena. Many ecological models consist of mathematical formulas based on data collected through observation and experimentation. Further observations by ecologists can be used to test predictions based on those models.

FIGURE 3–3 Ecology Field Work

The three fundamental approaches to ecological research involve observing, experimenting, and modeling. This ecologist is measuring a giant Rafflesia flower in Borneo.
3.2 Energy, Producers, and Consumers

THINK ABOUT IT At the core of every organism’s interaction with the environment is its need for energy to power life’s processes. Ants use energy to carry objects many times their size. Birds use energy to migrate thousands of miles. You need energy to get out of bed in the morning! Where does energy in living systems come from? How is it transferred from one organism to another?

Primary Producers

What are primary producers?
Living systems operate by expending energy. Organisms need energy for growth, reproduction, and their own metabolic processes. In short, if there is no energy, there are no life functions! Yet, no organism can create energy—organisms can only use energy from other sources. You probably know that you get your energy from the plants and animals you eat. But where does the energy in your food come from? For most life on Earth, sunlight is the ultimate energy source. Over the last few decades, however, researchers have discovered that there are other energy sources for life. For some organisms, chemical energy stored in inorganic chemical compounds serves as the ultimate energy source for life processes.

Only algae, certain bacteria, and plants like the one in Figure 3–4 can capture energy from sunlight or chemicals and convert it into forms that living cells can use. These organisms are called autotrophs. Autotrophs use solar or chemical energy to produce “food” by assembling inorganic compounds into complex organic molecules. But autotrophs do more than feed themselves. Autotrophs store energy in forms that make it available to other organisms that eat them. That’s why autotrophs are also called primary producers. Primary producers are the first producers of energy-rich compounds that are later used by other organisms. Primary producers are, therefore, essential to the flow of energy through the biosphere.

FIGURE 3–4 Primary Producers Plants obtain energy from sunlight and turn it into nutrients that can, in turn, be eaten and used for energy by animals such as this caterpillar.

Key Questions

What are primary producers?
How do primary producers obtain energy?

Vocabulary

autotroph • primary producer • photosynthesis • chemosynthesis • heterotroph • consumer • carnivore • herbivore • scavenger • omnivore • decomposer • detritivore

Taking Notes

Concept Map As you read, use the highlighted vocabulary words to create a concept map that organizes the information in this lesson.

BUILD Vocabulary

PREFIXES The prefix auto- means “by itself.” The Greek word trophikos means “to feed.” An autotroph can, therefore, be described as a “self feeder,” meaning that it does not need to eat other organisms for food.

Getting Started

Objectives

3.2.1 Define primary producers.
3.2.2 Describe how consumers obtain energy and nutrients.

Student Resources

Study Workbooks A and B, 3.2 Worksheets
Spanish Study Workbook, 3.2 Worksheets

For corresponding lesson in the Foundation Edition, see pages 60–62.

Build Background

Make a T-Chart on the board, and record students’ responses to the following questions: From what do you get energy? For what do you use energy? Students’ responses should indicate that they get energy from a variety of foods, and that they use energy for all of their activities and life processes. Tell students that all living things must obtain energy and that all living things use energy.

Study Wkbs A/B, Appendix S30, T-Chart.

Tutor Tube.

Students can review producers and consumers in Tutor Tube.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

CONTENT

C.4.b, C.5.a, C.5.b, C.5.e, C.5.f, D.1

INQUIRY

A.1.b, A.2.b
Lesson 3.2 • Tutor Tube

**Teach**

**Connect to Chemistry**

Point out the word equation summarizing the processes of photosynthesis in Figure 3–5. Explain that photosynthesis is often written using a chemical formula. Write it on the board:

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

Show students the correspondence between the word equation on this page and the chemical formula you wrote on the board.

Use this chemical summary of photosynthesis to start a discussion on how the process of photosynthesis affects the atmosphere. Point out that photosynthetic organisms remove carbon dioxide from the atmosphere and add oxygen to it. Tell students they will study the process of photosynthesis in more detail later in this book.

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** For students who have difficulty understanding the connection between photosynthesis and chemosynthesis, suggest they focus on Figure 3–5. Point out that both processes use energy to produce carbohydrates—energy-rich compounds that organisms can use to power life processes.

**Address Misconceptions**

*Energy in Biological Systems* Students may think that energy is formed, or created, by the processes of photosynthesis or chemosynthesis. Students may also believe organisms “use up,” or destroy, energy when carrying out life processes. Remind students that photosynthesis and chemosynthesis produce energy-rich compounds, but they do not produce energy. Explain that energy cannot be created or destroyed, but it can change form.

**Ask** Where does the energy for photosynthesis and chemosynthesis come from? *(The energy for photosynthesis comes from the energy in sunlight; the energy for chemosynthesis comes from the energy in the chemical bonds of inorganic molecules.)*

**Answers**

**FIGURE 3–5** Sample answer: Photosynthesis and chemosynthesis are similar in that both use energy to produce carbohydrates.

**IN YOUR NOTEBOOK** Sample answer: Photosynthetic producers use light energy to produce carbohydrates; chemosynthetic producers use chemical energy to produce carbohydrates. Photosynthetic and chemosynthetic producers are both autotrophs.

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**Quick Facts**

**POWERING LIFE**

Energy from the sun is a vital support of life on Earth. However, much more solar energy reaches Earth each day than is needed to support Earth’s producers. Most of the “extra” energy is absorbed or reflected by Earth’s surface and atmosphere. In fact, only about 0.06 percent of the solar energy that reaches Earth’s producers is converted to chemical energy through the process of photosynthesis. However, even that tiny fraction results in about 170 billion tons of organic matter every year.
**Consumers**

*How do consumers obtain energy and nutrients?*

Animals, fungi, and many bacteria cannot directly harness energy from the environment as primary producers do. These organisms, known as *heterotrophs* (hèr uh roh trohfs) must acquire energy from other organisms—by ingesting them in one way or another. Heterotrophs are also called *consumers.* Organisms that rely on other organisms for energy and nutrients are called consumers.

**Types of Consumers**

Consumers are classified by the ways in which they acquire energy and nutrients, as shown in Figure 3–6. As you will see, the definition of *food* can vary quite a lot among consumers.

- **Carnivores** kill and eat other animals. Carnivores include snakes, dogs, cats, and this giant river otter. Catching and killing prey can be difficult and requires energy, but meat is generally rich in nutrients and energy and is easy to digest.

- **Herbivores** like this military macaw obtain energy and nutrients by eating plant leaves, roots, seeds, or fruits. Common herbivores include cows, caterpillars, and deer.

- **Omnivores** are animals whose diets naturally include a variety of different foods that usually include both plants and animals. Humans, bears, pigs, and this white-nosed coati are omnivores.

- **Scavengers** are animals that consume the carcasses of other animals that have been killed by predators or have died of other causes. This king vulture is a scavenger.

- **Decomposers**, such as bacteria and fungi (like this mushroom), “feed” by chemically breaking down organic matter. The decay caused by decomposers is part of the process that produces detritus—small pieces of dead and decaying plant and animal remains.

- **Detritivores** (dee tryt uh rawvz) like this giant earthworm feed on detritus particles, often chewing or grinding them into even smaller pieces. Many types of mites, snails, shrimp, and crabs are detritivores. Detritivores commonly digest decomposers that live on, and in, detritus particles.

- **Detritivores** are animals that consume the carcasses of other animals that have been killed by predators or have died of other causes. This king vulture is a scavenger.

**Check for Understanding**

**HAND SIGNALS**

Present students with the following questions and ask them to show a thumbs-up sign if they understand, a thumbs-down sign if they are confused, or a waving-hand sign if they partially understand.

- How do producers make energy-rich compounds?
- How do consumers get the energy they need for life processes?
- What are some different categories of consumers?

**ADJUST INSTRUCTION**

Use students’ responses to gauge understanding of the topics covered in this lesson. If responses indicate that students are struggling with one or more of these topics, model for students how to make an outline of the lesson. Have each student make an outline, and then have students work in pairs to discuss the topics in their outlines.

**Use Visuals**

Have students examine Figure 3–6. Divide the class into six groups, and assign one type of consumer shown in the figure to each group. Tell students their group will have about 5 minutes to prepare several questions about their assigned consumer category. Collect the questions, read them to the class, and have volunteers answer any question they did not write. Then, discuss as a class any questions that students have difficulty answering.

**DIFFERENTIATED INSTRUCTION**

**ELL** Less Proficient Readers Have students complete a Frayer Model for each of the six types of consumers shown in Figure 3–6. For each type of consumer, have students write the name of it in the center box, a definition of it in the top left section, a drawing of it in the top right section, an example of it in the bottom left section, and a nonexample in the bottom right section.

**Study Wkbks A/B,** Appendix S26, Frayer Model. Transparencies, GO9.

**ELL** Focus on ELL:

**Build Background**

**BEGINNING AND INTERMEDIATE**

**SPEAKERS** Suggest students complete a Gallery Walk to build their knowledge of producers and consumers. Post eight sheets of chart paper around the classroom and label each with one of the following: photosynthetic autotroph, chemosynthetic autotroph, carnivore, scavenger, decomposer, herbivore, omnivore, and detritivore. Divide the class equally among the posters, and give a different-colored pen to each group. Have each group write down everything they know about the posted category of organisms. Encourage beginning speakers to draw example organisms. Then, have groups rotate through the posters evaluating previous groups’ work and adding any additional information they know.

**Study Wkbks A/B,** Appendix S6, Gallery Walk.

**Students can drag and drop labels over photographs of an ecosystem in Art Review: Producers and Consumers.**
Teach continued

**Quick Lab**

**PURPOSE** Students will identify producers and consumers.

**MATERIALS** 2 potted bean seedlings, 2 wide-mouth jars, aphids, flexible screening, 2 rubber bands, ladybird beetles, water

**SAFETY** Students should wash their hands after handling the organisms.

**PLANNING** Plant bean seedlings two weeks before this lab is performed. Order aphids and ladybird beetles to arrive shortly before the lab is scheduled.

**ANALYZE AND CONCLUDE**

1. In the jar with no beetles, the aphids harmed the seedling. Less damage to the plant was observed in the jar with beetles. This difference can be explained by the fact that the beetles ate some of the aphids, reducing the number of aphids feeding on the plant.

2. seedling, producer; aphid, consumer (herbivore); beetle, consumer (carnivore)

Have students review the role of detritivores and decomposers explained in Figure 3–6 and link this information to the bacterial community in Narragansett Bay. Students can go online to Biology.com to gather their evidence.

**Assess and RemEDIATE**

**EVALUATE UNDERSTANDING**

Write each lesson vocabulary term on a separate slip of paper, and place the slips in a container. Have volunteers draw two slips of paper, and use these two words to form a scientifically accurate sentence. Continue until all words have been drawn. Then, have students complete the 3.2 Assessment.

**REMEDICATION SUGGESTION**

- Struggling Students Have students list examples of decomposers and detritivores if they have difficulty answering Question 2b.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

**Assessment Answers**

1a. solar energy and chemical energy

1b. Sample answer: How do organisms that live so deep in the ocean get the energy they need to live?

2a. Consumers get energy by ingesting other organisms or the remains of organisms.

2b. Detritivores are different from decomposers because detritivores feed by eating detritus particles, while decomposers feed by chemically breaking down organic matter on which they live. Decomposers actually produce detritus. In turn, detritivores often consume decomposers that live among detritus.

3. The Greek word heteros means “other,” or “different.”
3.3 Energy Flow in Ecosystems

THINK ABOUT IT What happens to energy stored in body tissues when one organism eats another? That energy moves from the “eaten” to the “eater.” You’ve learned that the flow of energy through an ecosystem always begins with either photosynthetic or chemosynthetic primary producers. Where it goes from there depends literally on who eats whom!

Food Chains and Food Webs

How does energy flow through ecosystems?
In every ecosystem, primary producers and consumers are linked through feeding relationships. Despite the great variety of feeding relationships in different ecosystems, energy always flows in similar ways. Energy flows through an ecosystem in a one-way stream, from primary producers to various consumers.

Food Chains You can think of energy as passing through an ecosystem along a food chain. A food chain is a series of steps in which organisms transfer energy by eating and being eaten. Food chains can vary in length. For example, in a prairie ecosystem, a primary producer, such as grass, is eaten by an herbivore, such as a grazing antelope. A carnivore, such as a coyote, in turn feeds upon the antelope. In this two-step chain, the carnivore is just two steps removed from the primary producer.

In some aquatic food chains, primary producers are a mixture of floating algae called phytoplankton and attached algae. As shown in Figure 3–7, these primary producers may be eaten by small fishes, such as flagfish. Larger fishes, like the largemouth bass, eat the small fishes. The bass are preyed upon by large wading birds, such as the anhinga, which may ultimately be eaten by an alligator. There are four steps in this food chain. The top carnivore is therefore four steps removed from the primary producer.

In some aquatic food chains, primary producers are a mixture of floating algae called phytoplankton and attached algae. As shown in Figure 3–7, these primary producers may be eaten by small fishes, such as flagfish. Larger fishes, like the largemouth bass, eat the small fishes. The bass are preyed upon by large wading birds, such as the anhinga, which may ultimately be eaten by an alligator. There are four steps in this food chain. The top carnivore is therefore four steps removed from the primary producer.

Key Questions

- How does energy flow through ecosystems?
- What do the three types of ecological pyramids illustrate?

Vocabulary

- food chain
- phytoplankton
- food web
- zooplankton
- trophic level
- ecological pyramid
- biomass

Taking Notes

Preview Visuals Before you read, look at Figure 3–7 and Figure 3–9. Note how they are similar and how they are different. Based on the figures, write definitions for food chain and food web.

FIGURE 3–7 Food Chains Food chains show the one-way flow of energy in an ecosystem. Apply Concepts What is the ultimate source of energy for this food chain?

Primary producer Herbivore Carnivore

Algae Flagfish Largemouth bass Anhinga Alligator

Teach for Understanding

ENDURING UNDERSTANDING The existence of life on Earth depends on interactions among organisms and between organisms and their environment.

GUIDING QUESTION How does energy move through an ecosystem?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand food chains and how energy moves through ecosystems. Have students write a creative story about the organisms that live and interact in a fictitious ecosystem. Explain that another student should be able to construct a food web for this ecosystem from the details that they include in their stories. Then, have partners exchange stories and draw each other’s food webs.

Getting Started

Objectives

3.3.1 Trace the flow of energy through living systems.
3.3.2 Identify the three types of ecological pyramids.

Student Resources

Study Workbooks A and B, 3.3 Worksheets
Spanish Study Workbook, 3.3 Worksheets
Lab Manual B, 3.3 Data Analysis Worksheet

Answers

FIGURE 3–7 sunlight

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Teach

Use Models

Explain that food chains and food webs are types of models. Remind students that modeling is one of three methods used in ecological studies.

**Ask** Why might scientists study feeding relationships using a model, such as a food chain or food web? (Sample answer: Feeding relationships may be difficult to observe, and it may be unethical to experiment with them.)

**Ask** What type of predictions could be made using a food chain or food web? (Sample answer: A food web could be used to predict what would happen if a certain population in an ecosystem increased or decreased in size.)

**DIFFERENTIATED INSTRUCTION**

**Special Needs** Show students a picture of a spider web. Have them compare the spider web to a food web.

**Ask** In what way is a spider's web similar to a food web? (Sample answer: There are many different connections in both kinds of web.)

**FIGURE 3–8** Earth’s Recycling Center

Decomposers break down dead organic matter and release nutrients back into the environment. They recycle nutrients like a city recycling center recycles paper or plastic.

**IN YOUR NOTEBOOK** A food chain is a portion of a food web. It shows how energy moves from one organism to the next as they feed on one another. A food web is a more complex and complete representation of the feeding relationships in an entire ecosystem.

**Answers**

**FIGURE 3–8** Decomposers break down dead organic matter and release nutrients back into the environment. They recycle nutrients like a city recycling center recycles paper or plastic.

**IN YOUR NOTEBOOK** A food chain is a portion of a food web. It shows how energy moves from one organism to the next as they feed on one another. A food web is a more complex and complete representation of the feeding relationships in an entire ecosystem.

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**Food Webs** In most ecosystems, feeding relationships are much more complicated than the relationships described in a single, simple chain. One reason for this is that many animals eat more than one kind of food. For example, on Africa’s Serengeti Plain, herbivores, such as zebras, gazelles, and buffaloes, often graze upon several different species of grasses. Several predators such as lions, hyenas, and leopards, in turn, often prey upon those herbivores! Ecologists call this network of feeding interactions a **food web**.

**Food Chains Within Food Webs** The Everglades are a complex marshland ecosystem in southern Florida. Here, aquatic and terrestrial organisms interact in many overlapping feeding relationships that have been simplified and represented in **Figure 3–9**. Starting with a primary producer (algae or plants), see how many different routes you can take to reach the alligator, vulture, or anhinga. One path, from the algae to the alligator, is the same food chain you saw in **Figure 3–7**. In fact, each path you trace through the food web is a food chain. You can think of a food web, therefore, as linking together all of the food chains in an ecosystem. Realize, however, that this is a highly simplified representation of this food web, in which many species have been left out. Now, you can begin to appreciate how complicated food webs are!

**Decomposers and Detritivores in Food Webs** Decomposers and detritivores are as important in most food webs as other consumers are. Look again at the Everglades web. Although white-tailed deer, moorhens, raccoons, grass shrimp, crayfish, and flagfish feed at least partly on primary producers, most producers die without being eaten. In the detritus pathway, decomposers convert that dead material to detritus, which is eaten by detritivores, such as crayfish, grass shrimp, and worms. At the same time, the decomposition process releases nutrients that can be used by primary producers. Thus, decomposers recycle nutrients in food webs as seen in **Figure 3–8**. Without decomposers, nutrients would remain locked within dead organisms.

**Biology In-Depth**

**Composting**

Composting is a process that uses decomposers, and sometimes detritivores, to decompose organic wastes. Household composting is usually performed using food and yard wastes. Decomposers break down these organic materials, much as they would in a natural setting. The resulting material, called compost, is full of nutrients and is used to enrich soil. Home composting can range from passive (just throw everything into a pile) to highly controlled. Controlled composting may involve the manipulation of conditions such as temperature, moisture, and oxygen levels to maximize decomposer activity.
FIGURE 3–9 Food Web in the Everglades. This illustration of a food web shows some of the feeding relationships within the Florida Everglades. The orange-highlighted food chain from Figure 3–7 is one of many that make up this food web. Interpret Visuals: Describe three food chains that are part of this food web.

Use Visuals
Students can use Figure 3–9 to examine feeding relationships in an ecosystem and to review the categories of organisms that make up a food web.

Ask What primary producers are shown in this food web? (plants, leaves, seeds, fruit, algae)

Ask What can you infer about vultures from this food web? (Sample answer: They eat animals that are already dead.)

DIFFERENTIATED INSTRUCTION

L1 Struggling Students Have students use Figure 3–9 to examine the structure of a food web and to compare food webs and food chains.

Ask What do the orange arrows in the diagram show? (the food chain from Figure 3–7)

Ask How does the food chain compare to the food web? (Sample answer: The food chain is a much simpler diagram; the food web is a more complete representation of the energy flow in an ecosystem.)

ELL Focus on ELL: Access Content

ALL SPEAKERS Have students work in groups to make a food chain or a food web, using pictures from magazines. Integrate beginning speakers with intermediate, advanced, and advanced high speakers. Have beginning speakers use single written or spoken words to describe the components of their food chain or food web. Intermediate speakers should describe their food chain or food web using simple sentences. Challenge advanced and advanced high speakers to compare and contrast a food chain and food web.

Check for Understanding

FOLLOW-UP PROBES

Ask Why is a food web a more accurate representation of the feeding relationships in an ecosystem than a food chain? (An organism is rarely food for or feeds on just one other organism; a food web shows the many different feeding relationships that exist between organisms in an ecosystem.)

ADJUST INSTRUCTION

If responses indicate that students do not understand why a food web is a more accurate representation of feeding relationships than a food chain, have them discuss the foods they eat on a typical day. Point out that they consume foods from many different sources. Explain that most living things feed on more than one type of food, and many living things are themselves food for many other types of organisms.

Answers

FIGURE 3–9 Students should identify three food chains in the food web. Sample answer: Plants are eaten by raccoons; raccoons are eaten by alligators.
Food Webs and Disturbance  Food webs are complex, so it is often difficult to predict exactly how they will respond to environmental change. Look again at Figure 3–9, and think about the questions an ecologist might ask about the feeding relationships in it following a disturbance. What if an oil spill, for example, caused a serious decline in the number of the bacteria and fungi that break down detritus? What effect do you think that might have on populations of crayfish? How about the effects on the grass shrimp and the worms? Do you think those populations would decline? If they did decline, how might pig frogs change their feeding behavior? How might the change in frog behavior then affect the other species on which the frog feeds?

Relationships in food webs are not simple, and, as you know, the food web in Figure 3–9 has been simplified! So, you might expect that answers to these questions would not be simple either, and you'd be right. However, disturbances do happen, and their effects can be dramatic. Consider, for example, one of the most important food webs in the southern oceans. All of the animals in this food web, shown in Figure 3–10, depend directly or indirectly on shrimplike animals called krill, which feed on marine algae. Krill are one example of a diverse group of small, swimming animals, called zooplankton, that feed on marine algae. Adult krill browse on algae offshore, while their larvae feed on algae that live beneath floating sea ice. In recent years, krill populations have dropped substantially. Over that same period, a large amount of sea ice around Antarctica has melted. With less sea ice remaining, there are fewer of the algae that grow beneath the ice. Given the structure of this food web, a drop in the krill population can cause drops in the populations of all other members of the food web shown.

Answers

FIGURE 3–10 Krill are the only herbivores in this food web; without krill, the animals the killer whale eats would not survive.

How Science Works

USING ISOTOPES TO STUDY FOOD WEBS

Stable isotopes are naturally occurring, nonradioactive forms of atoms. For example, stable isotopes of carbon and nitrogen include carbon 12 ($^{12}$C), carbon 13 ($^{13}$C), nitrogen 14 ($^{14}$N), and nitrogen 15 ($^{15}$N). In any given tissue sample, there is a certain amount of all of these isotopes. Finding the ratio of carbon isotopes to each other, as well as the ratio of nitrogen isotopes, helps scientists investigate the donor organism’s relative trophic level within an ecosystem. This technique is based on the finding that organisms tend to selectively metabolize the lighter isotopes of carbon and nitrogen ($^{12}$C and $^{14}$N). So, organisms in higher trophic levels often accumulate more of the heavier isotopes ($^{12}$C and $^{14}$N) relative to the lighter ones. In fact, an organism’s $^{15}$N ratio tends to be about 0.3 percent higher than that of the organisms it eats.
Trophic Levels and Ecological Pyramids

What do the three types of ecological pyramids illustrate?

Each step in a food chain or food web is called a trophic level. Primary producers always make up the first trophic level. Various consumers occupy every other level. One way to illustrate the trophic levels in an ecosystem is with an ecological pyramid.

Ecological pyramids show the relative amount of energy or matter contained within each trophic level in a given food chain or food web. There are three different types of ecological pyramids: pyramids of energy, pyramids of biomass, and pyramids of numbers.

In Your Notebook Make a two-column chart to compare the three types of ecological pyramids.

Pyramids of Energy Theoretically, there is no limit to the number of trophic levels in a food web or the number of organisms that live on each level. But there is one catch. Only a small portion of the energy that passes through any given trophic level is ultimately stored in the bodies of organisms at the next level. This is because organisms expend much of the energy they acquire on life processes, such as respiration, movement, growth, and reproduction. Most of the remaining energy is released into the environment as heat—a byproduct of these activities. Pyramids of energy show the relative amount of energy available at each trophic level of a food chain or food web.

The efficiency of energy transfer from one trophic level to another varies. On average, about 10 percent of the energy available within one trophic level is transferred to the next trophic level, as shown in Figure 3–11. For instance, one tenth of the solar energy captured and stored in the leaves of grasses ends up stored in the tissues of cows and other grazers. One tenth of that energy—10 percent of 10 percent, or 1 percent of the original amount—gets stored in the tissues of humans who eat cows. Thus, the more levels that exist between a producer and a given consumer, the smaller the percentage of the original energy from producers that is available to that consumer.

Apply Concepts Explain how the amount of energy available at each trophic level often limits the number of organisms that can support.

FIGURE 3–11 Pyramid of Energy Pyramids of energy show the relative amount of energy available at each trophic level. An ecosystem requires a constant supply of energy from photosynthetic or chemosynthetic producers. Apply Concepts Explain how the amount of energy available at each trophic level often limits the number of organisms that can support.

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The 10 Percent Rule

As shown in Figure 3–11, an energy pyramid is a diagram that illustrates the transfer of energy through a food chain or food web. In general, only 10 percent of the energy available in one level is stored in the level above. Look at Figure 3–11 and answer the questions below.

1. Calculate If there are 1000 units of energy available at the producer level of the energy pyramid, approximately how many units of energy are available to the third-level consumer?

2. Infer Why are there usually fewer organisms in the top levels of an energy pyramid?

3. Infer Why are there usually fewer organisms in the top levels of an energy pyramid?

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Build Math Skills

Have students examine Figure 3–11. Point out that the percentages shown at each level of the pyramid of energy are percentages of the original energy entering the food chain. Explain that, at each transfer, about 10 percent of the energy from one trophic level is available to move to the organisms at the next trophic level.

Ask If this food chain included fourth-level consumers, what percentage of the original energy would be available to those organisms? (0.01%)

DIFFERENTIATED INSTRUCTION

Struggling Students For students who have difficulty with the percentages in Figure 3–11, model the relative loss of energy using example numbers and organisms. Tell students to suppose that a particular plant produces 200 Calories worth of food. Ninety percent of this is either used to power the plant’s life processes or lost as heat. Therefore, only 10 percent of the 200 Calories will be available to a mouse (first-level consumer) that eats the plant. On the board, show how to calculate 10 percent of 200 Calories. Write:

200 Calories (0.10) = 20 Calories

Then, explain that of this 20 Calories, only 10 percent will be available to an owl (second-level consumer) that eats the mouse. Write:

20 Calories (0.10) = 2 Calories

Using this example, make sure students understand the overarching concept: only a small part of the energy an organism takes in during its lifetime can be passed to the next organism in the food chain.

Answers

FIGURE 3–11 A trophic level cannot contain more organisms than there is energy to support.

IN YOUR NOTEBOOK Students’ charts should list the three types of pyramids in the left column and facts about each type in the right column.
ASSIGNMENT 3.3

Teach continued

Lead a Discussion

Make sure students can differentiate between a biomass pyramid and a pyramid of numbers.

Ask Which pyramid shows the amount of organic matter at each trophic level? (biomass pyramid)

DifferenTIATeD ISTRUCTION

L Advanced Students Have students write a paragraph comparing and contrasting food webs and ecological pyramids. Their paragraph should identify two similarities and two differences.

Assess and RemEDIATE

EVALUATE UNDERSTANDING

On the board, write the question: How does energy move through an ecosystem? Have each student write a short response. Call on volunteers to share their responses with the class. Then, have students complete the 3.3 Assessment.

REMEDICATION SUGGESTION

L Struggling Students If students have difficulty answering Question 3, suggest they use a finger to trace over the arrows that connect organisms to help them find and follow a food chain within the food web.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. Sample answer: Energy is not recycled. Energy enters an ecosystem and flows through a food chain, but it is not reused—it is lost as heat.

1b. Sample answer: A decrease in the population of crayfish would likely result in less food available to raccoons, pigs, frogs, and anhingas. These populations might decrease. Populations on which the crayfish feed, such as plants, detritus, and grass shrimp, may increase.

2a. About 10 percent of the energy at any trophic level is passed to the next trophic level. The remainder of the energy is used for life processes or released into the environment as heat.

2b. Students’ pyramids should show 100% of the energy available at the first level, 10% at the second level, 1% at the third level, 0.1% at the fourth level, and 0.01% at the fifth level.

3. Students may choose and describe any of the food chains in Figure 3–9. Check that the food chains contain a primary producer and at least one consumer.

Pyramids of Biomass and Numbers The total amount of living tissue within a given trophic level is called its biomass. Biomass is usually measured in grams of organic matter per unit area. The amount of biomass a given trophic level can support is determined, in part, by the amount of energy available.

A pyramid of biomass illustrates the relative amount of living organic matter available at each trophic level in an ecosystem.

Ecologists interested in the number of organisms at each trophic level use a pyramid of numbers.

A pyramid of numbers shows the relative number of individual organisms at each trophic level in an ecosystem. In most ecosystems, the shape of the pyramid of numbers is similar to the shape of the pyramid of biomass for the same ecosystem. In this shape, the numbers of individuals on each level decrease from the level below it. To understand this point more clearly, imagine that an ecologist marked off several square meters in a field, and then weighed and counted every organism in that area. The result might look something like the pyramid in Figure 3–12.

In some cases, however, consumers are much less massive than organisms they feed upon. Thousands of insects may graze on a single tree, for example, and countless mosquitoes can feed off a few deer. Both the tree and deer have a lot of biomass, but they each represent only one organism. In such cases, the pyramid of numbers may be turned upside down, but the pyramid of biomass usually has the normal orientation.

FIGURE 3–12 Pyramids of Biomass and Numbers

In most cases, pyramids of biomass and numbers follow the same general pattern. In the field modeled here, there are more individual primary consumers than first-level consumers. Likewise, the primary producers collectively have more mass. The same patterns hold for the second and third-level consumers. With each step to a higher trophic level, biomass and numbers decrease.

FIGURE 3–12

Chapter 3 • Lesson 3
Recycling in the Biosphere

**How does matter move through the biosphere?**

Matter moves through the biosphere differently than the way in which energy moves. Solar and chemical energy are captured by primary producers and then pass in a one-way fashion from one trophic level to the next—dissipating in the environment as heat along the way. But while energy in the form of sunlight is constantly entering the biosphere, Earth doesn’t receive a significant, steady supply of new matter from space. Unlike the one-way flow of energy, matter is recycled within and between ecosystems. Elements pass from one organism to another and among parts of the biosphere through closed loops called **biogeochemical cycles**, which are powered by the flow of energy as shown in Figure 3–13. As that word suggests, cycles of matter involve biological processes, geological processes, and chemical processes. Human activity can also play an important role. As matter moves through these cycles, it is transformed. It is never created or destroyed—just changed.
LEsson 3.4

Teach

Lead a Discussion
As a class, discuss the different types of processes that cycle matter through the biosphere. Take a minute to talk about why human activity is discussed separately from biological processes.

**Ask** Why would the breakdown of rock by ocean waves be considered a geological process, but the breakdown of rock by tree roots be considered a biological process? (because the latter involves a living organism)

**Ask** Why might human activities be considered a separate category from other biological processes involving living organisms? (because human activities have such a large impact on the ecosystem beyond the simple acts of eating, respiring, and eliminating wastes)

As students work through the lesson, suggest they take note of how humans influence different biogeochemical cycles.

**Differentiated Instruction**

**ELL** English Language Learners Before students read through the lesson and begin discussing the content, prepare a handout that lists the Key Questions and their answers. Be sure the answers are presented in simple sentences. Have students review the handout and underline any unfamiliar words. Then, have them use the Glossary or a dictionary to find the meaning of unfamiliar words. After students complete the lesson, have them work with a partner to review the handout by asking and answering the questions.

**LPR** Less Proficient Readers Suggest students use the visuals as a reference while you discuss the different ways matter cycles through the biosphere. Talk about why each photo is a good representation of the type of process it is showing.

**Quick Facts**

**Precipitation and Evaporation**

Huge quantities of water cycle between Earth’s surface and atmosphere. Hydrologists estimate that about 577,000 cubic kilometers of water evaporate from Earth’s surface (ocean and land surfaces combined) and enter the atmosphere each year. Considering all forms of precipitation, about 80 percent falls on oceans and about 20 percent on land. However, this same proportion does not hold true for water that evaporates from Earth’s surface: approximately 505,000 cubic kilometers (88 percent) of the water in the atmosphere comes from oceans and only about 72,000 cubic kilometers (12 percent) from land. The reason for the difference in proportions is simple: about a third of the precipitation that falls on land runs off into streams and rivers and is carried to oceans annually.
The Water Cycle

 cómo water cycle through the biosphere?

Every time you see rain or snow, or watch a river flow, you are witnessing part of the water cycle. Water continuously moves between the oceans, the atmosphere, and land—sometimes outside living organisms and sometimes inside them. As Figure 3–15 shows, water molecules typically enter the atmosphere as water vapor, a gas, when they evaporate from the ocean or other bodies of water. Water can also enter the atmosphere by evaporating from the leaves of plants in the process of transpiration (trans puh ray shun).

Water vapor may be transported by winds over great distances. If the air carrying it cools, water vapor condenses into tiny droplets that form clouds. When the droplets become large enough, they fall to Earth’s surface as precipitation in the form of rain, snow, sleet, or hail. On land, some precipitation flows along the surface in what scientists call runoff, until it enters a river or stream that carries it to an ocean or lake. Precipitation can also be absorbed into the soil and is then called groundwater. Groundwater can enter plants through their roots, or flow into rivers, streams, lakes, or oceans. Some groundwater penetrates deeply enough into the ground to become part of underground reservoirs. Water that re-enters the atmosphere through transpiration or evaporation begins the cycle anew.

In Your Notebook Define each of the following terms and describe how they relate to the water cycle: evaporation, transpiration, precipitation, and runoff.

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In Your Notebook Define each of the following terms and describe how they relate to the water cycle: evaporation, transpiration, precipitation, and runoff.

Evaporation is the process by which water changes from a liquid to a vapor. Water that evaporates enters the atmosphere. Transpiration is the evaporation of water from plant leaves. Precipitation occurs when water in the atmosphere condenses and falls to Earth’s surface. Runoff is precipitation that flows along Earth’s surface.

Check for Understanding

INDEX CARD SUMMARIES

Give each student an index card. Ask students to write one concept about the water cycle that they understand on the front of the card. Have them identify something about the water cycle that they do not understand, and write it on the back of the card in the form of a question.

ADJUST INSTRUCTION

Read over students’ cards to identify concepts about the water cycle that are causing confusion for one or more students. Write these topics on the board. Have students use their texts to find facts, lesson vocabulary terms, Key Questions, or other information relevant to each topic. Ask volunteers to share what they have learned with the class, and record their input on the board.

Use Visuals

Have students use Figure 3–15 to visualize the paths that water molecules can take in the water cycle.

Ask How are transpiration and evaporation similar? (Transpiration and evaporation are processes by which water enters the atmosphere.)

Ask How are transpiration and evaporation different? (Transpiration is a biological process; evaporation is a physical/chemical process.)

Ask Do water molecules always follow the same steps though the water cycle? (No, there is not a single series of steps in the water cycle.)

DIFFERENTIATED INSTRUCTION

Advanced Students Have students write a paragraph describing how humans and other land animals are involved in the water cycle. In particular, have students consider the role of respiration, a process by which water vapor is released into the air.

Students can see an animation of the water cycle in InterActive Art: The Water Cycle.

Answers

FIGURE 3–15 Water that falls as precipitation moves to rivers, lakes, and oceans as surface runoff or seeps into the ground and becomes groundwater.

IN YOUR NOTEBOOK Evaporation is the process by which water evaporates from a liquid to a vapor. Water that evaporates enters the atmosphere. Transpiration is the evaporation of water from plant leaves. Precipitation occurs when water in the atmosphere condenses and falls to Earth’s surface. Runoff is precipitation that flows along Earth’s surface.
LESSON 3.4

**Build Reading Skills**

Explain that the information about the carbon cycle on this page is also contained in Figure 3–17 on the next page. As students read the lesson, have them refer to the figure as each process in the carbon cycle is described.

**DIFFERENTIATED INSTRUCTION**

**ELL English Language Learners** Have students practice pronouncing terms associated with the carbon cycle by having them provide an answer to the following question aloud:

**Ask** What are some compounds and materials that carbon is a part of? (Sample answers: carbon dioxide, calcium carbonate, fossil fuels, carbonate rocks, carbohydrates, lipids, proteins, nucleic acids)

**Address Misconceptions**

Conservation of Matter Students might not understand that matter—like energy—is conserved in the biosphere. Explain that atoms cannot be created or destroyed. They are instead combined and recombined with other atoms to form different compounds. To help, refer students to the last two paragraphs on page 80, which describe how a carbon molecule may cycle through the biosphere.

**BUILD Vocabulary**

ACADEMIC WORDS The verb accumulate means “to collect or gather.” Carbon accumulates, or collects, in soil and in the oceans where it cycles among organisms or is turned into fossil fuels.

**FIGURE 3–16 Oxygen in the Biosphere** The oxygen contained in the carbon dioxide exhaled by this bighorn sheep may be taken up by producers and re-released as oxygen gas. Together, respiration and photosynthesis contribute to oxygen’s cycling through the biosphere.

**FIGURE 3–17** shows how carbon moves through the biosphere. Carbon dioxide is continuously exchanged between the atmosphere and oceans through chemical and physical processes. Plants take in carbon dioxide during photosynthesis and use the carbon to build carbohydrates. Carbohydrates then pass through food webs to consumers. Many animals—both on land and in the sea—combine carbon with calcium and oxygen as the animals build skeletons of calcium carbonate. Organisms release carbon in the form of carbon dioxide gas by respiration. Also, when organisms die, decomposers break down the bodies, releasing carbon to the environment. Geologic forces can turn accumulated carbon into carbon-containing rocks or fossil fuels. Carbon dioxide is released into the atmosphere by volcanic activity or by human activities, such as the burning of fossil fuels and the clearing and burning of forests.

**Quick Facts**

**THE CARBON POOL**

According to Climate Change 2007, a report by the Intergovernmental Panel on Climate Change (IPCC), the biosphere’s total carbon pool—the total mass of carbon atoms—is estimated to be approximately 44,750 metric gigatons. (1 metric gigaton equals 10^15 metric tons.) Of that total, about 85 percent is contained in Earth’s oceans and marine biota. About 8 percent of the carbon pool is contained in fossil fuels. About 5 percent is contained in vegetation, soil, and detritus. Only about 1 percent of the carbon pool is in the atmosphere and less than 1 percent is contained in surface sediments.
Scientists know a great deal about the biological, geological, chemical, and human processes that are involved in the carbon cycle, but important questions remain. How much carbon moves through each pathway? How do ecosystems respond to changes in atmospheric carbon dioxide concentration? How much carbon dioxide can the ocean absorb? Later in this unit, you will learn why answers to these questions are so important.

**In Your Notebook** Describe one biological, one geological, one chemical, and one human activity that is involved in the carbon cycle.

---

**Use Visuals**

Have students use Figure 3–17 to distinguish the biological, human, geological, and physical/chemical processes that are involved in the carbon cycle. Point out that each set of processes is designated by arrows of a specific color in the figure. (The same colors are used in Figures 3–14, 3–15, 3–18, and 3–19.)

**Ask** Why does the process of fossil fuel formation start as a biological process and end as geological one? (because geological forces turn biological, or organic matter, into carbon-containing rocks or fossil fuels)

**Ask** How are human activities affecting carbon reservoirs? (Human activities are taking carbon from fossil fuels and forests and adding it to the atmosphere.)

---

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** Some students might be overwhelmed by the complexity of the carbon cycle. Divide the class into four groups, and assign each group one of the four sets of processes in the diagram (biological, human, geological, or physical/chemical). Have students in each group work together to become “experts” on their assigned portion of the carbon cycle. Then, have each group give a brief presentation to share its expertise with the rest of the class.

---

**Check for Understanding**

**ONE-MINUTE RESPONSE**

Give students about a minute to write a short paragraph explaining why the carbon cycle is important for sustaining life on Earth. (Paragraphs should mention that carbon is a major component of organisms and is important in the process of photosynthesis.)

**ADJUST INSTRUCTION**

If students’ responses reveal confusion about the importance of the carbon cycle, suggest they work in pairs to review the information on the carbon cycle. Then, have pairs write a new, more comprehensive explanation of why the carbon cycle is important for life.

---

**Answers**

**FIGURE 3–17** Sample answer: Photosynthesis is a process that takes carbon dioxide out of the atmosphere.

**IN YOUR NOTEBOOK** Sample answer: Photosynthesis is a biological activity that removes carbon dioxide from the atmosphere; volcanic activity is a geologic process that releases carbon dioxide into the atmosphere; dissolving is a physical/chemical process that removes carbon dioxide from the atmosphere; and burning of fossil fuels is a human activity that releases carbon dioxide into the atmosphere.
LESSON 3.4

Lead a Discussion

Have students use the information in Figure 3–18 to review the nitrogen cycle.

Ask How do humans affect the nitrogen cycle? (Humans take nitrogen gas from the atmosphere to create fertilizers. When these fertilizers are applied to crops, excess can wash into rivers, streams, and oceans, resulting in increased nitrogen levels.)

Ask What biological process converts nitrogen gas to ammonia? (nitrogen fixation)

DIFFERENTIATED INSTRUCTION

S Special Needs Ask the following questions to help students focus on the importance of cycling of matter to life on Earth.

Ask Why do living things need nitrogen? (Nitrogen is used to make proteins, which are a part of living things’ bodies.)

Ask What would happen if the processes in the nitrogen cycle stopped? (The nitrogen that living things need would not be available, and living things would die as a result.)

Since human activity hasn’t changed much, something else must be adding nitrogen to the bay. Using Figure 3–18, lead students to conclude that the bacteria that fix nitrogen have increased, leading to an increase in nitrogen in the bay. Students can go online to Biology.com to gather their evidence.

Answers

FIGURE 3–18 Bacteria convert nitrogen gas to ammonia through the process of nitrogen fixation. This ammonia is converted to nitrates and nitrites. Lightning also fixes nitrogen gas.

Quick Facts

THE SCARCITY OF USABLE NITROGEN

Nitrogen is abundant in the atmosphere; in fact, it makes up 78 percent of Earth’s atmosphere. However, usable forms of nitrogen are scarce in ecosystems. The reason for this is the structure of N₂ gas. It is held together by triple covalent bonds that lightning and certain bacteria can break. Bacteria that fix nitrogen use nitrogenase, an enzyme, to break the covalent bonds in N₂ molecules and produce a form of nitrogen that living things can use. Nitrogenase can function only when it is isolated from oxygen. On land, nitrogen-fixing bacteria are found in the oxygen-excluding environments of root nodules or insulating slime on plant roots. In aquatic ecosystems, cyanobacteria, the primary nitrogen-fixers, have specialized cells called heterocysts that exclude oxygen.
The Phosphorus Cycle  Phosphorus is essential to living organisms because it forms a part of vital molecules such as DNA and RNA. Although phosphorus is of great biological importance, it is not abundant in the biosphere. Unlike carbon, oxygen, and nitrogen, phosphorus does not enter the atmosphere in significant amounts. Instead, phosphorus in the form of inorganic phosphate remains mostly on land, in the form of phosphate rock and soil minerals, and in the ocean, as dissolved phosphate and phosphate sediments, as seen in Figure 3–19.

As rocks and sediments gradually wear down, phosphate is released. Some phosphate stays on land and cycles between organisms and soil. Plants bind phosphate into organic compounds when they absorb it from soil or water. Organic phosphate moves through the food web, from producers to consumers, and to the rest of the ecosystem. Other phosphate washes into rivers and streams, where it dissolves. This phosphate may eventually make its way to the ocean, where marine organisms process and incorporate it into biological compounds.

Nutrient Limitation

How does nutrient availability relate to the primary productivity of an ecosystem?

Ecologists are often interested in an ecosystem’s primary productivity—the rate at which primary producers create organic material. If ample sunlight and water are available, the primary productivity of an ecosystem may be limited by the availability of nutrients. If even a single essential nutrient is in short supply, primary productivity will be limited. The nutrient whose supply limits productivity is called the limiting nutrient.

Connect to the Real World

Tell students that at one time, phosphates were an important component of most laundry detergents used in the United States.

Ask If wastewater containing phosphates from laundry detergent made its way into waterways, such as streams, rivers, and lakes, how would that affect the phosphorus cycle? (It would result in an increase in phosphates in water ecosystems.)

Ask What is one other way human activity affects the phosphorus cycle? (The application of fertilizers that contain phosphorus can increase phosphates in aquatic ecosystems.)

DIFFERENTIATED INSTRUCTION

Less Proficient Readers  Have students use the arrows and embedded labels in Figure 3–19 to help them answer the following questions about the effects of phosphate-laden laundry detergents.

Ask If phosphates were still part of laundry detergent, what color arrow would be used in the diagram to show the flow of phosphates from laundry detergent into waterways? Why? (Orange, because orange arrows are used to show how human activity impacts the phosphorus cycle.)

Ask What would you add to the visual to show how phosphates from laundry detergent entered the phosphorus cycle? (I would draw an orange arrow coming from human homes and entering the river. I would label this arrow to explain how laundry wastewater carried phosphates into waterways.)

Advanced Students  Have students research the impact that phosphates in laundry detergent had on aquatic ecosystems. Also, have them learn about government and industry actions that eliminated most phosphates from laundry detergents. Ask students to prepare a presentation on this topic. Remind them to relate what they find out to the information about the phosphate cycle in the text.

Students can see how the carbon, nitrogen, and phosphorus cycles are connected in the Visual Analogy: Interlocking Nutrient Cycles.
**Teach continued**

**Visual Analogy**

Have students examine Figure 3–20. Tell them that, like these gears, the nutrient cycles in the biosphere are interdependent. Explain that, in this analogy, the slowest-moving gear represents the limiting nutrient in an ecosystem.

**Assess and Remediate**

**Evaluate Understanding**

Call on volunteers to name a matter cycle that occurs in the biosphere. Then, ask additional volunteers to supply details about that cycle. Continue until each cycle has been thoroughly described. Then, have students complete the 3.4 Assessment.

**Remediation Suggestion**

- **Struggling Students** If students have difficulty answering Question 5, explain that the chemical symbol for oxygen is $O$. Have them use Figure 3–17 to determine how oxygen atoms move through the biosphere as part of the carbon cycle.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

**Answers**

**Figure 3–20** nitrogen

**Assessment Answers**

1a. Matter is recycled through ecosystems; no new matter is generated. Energy is continually input into ecosystems, and moves through ecosystems in a one-way path.

1b. Sample answers: biological, such as respiration; geological, such as volcanic eruptions; chemical/physical, such as precipitation; human activity, such as burning fossil fuels

2a. Review and transpiration

2b. Sample answer: Water from the ocean evaporates into the atmosphere. It falls to land as precipitation, and then flows into the ocean as surface runoff.

3a. Organisms need nutrients to build tissues and carry out life functions.

3b. If vast amounts of forests are cleared and burned, levels of atmospheric carbon dioxide will likely increase.

4a. Most primary producers need sunlight, water, and nutrients to carry out photosynthesis. If water and sunlight are in ample supply, it is the amount of nutrients that limits the primary productivity.

4b. Fertilizer runoff can supply a large amount of nitrogen and/or phosphorus to an aquatic ecosystem. The algae in the ecosystem may suddenly have a much larger supply of the limiting nutrient in the ecosystem, producing an algal bloom.

**Write About Science**

5. Oxygen is a component of carbon dioxide in the atmosphere. During the process of photosynthesis, carbon dioxide is taken up and atmospheric oxygen is released. During cellular respiration, oxygen is combined with carbon and released in the form of carbon dioxide. Oxygen is also found in calcium carbonate, which is a part of animal skeletons and some rocks.
Global Ecology From Space

Can ecologists track plant growth around the world? Can they follow temperature change in oceans from day to day, or the amount of polar ice from year to year? Yes! Satellites can provide these data, essential for understanding global ecology. Satellite sensors can be programmed to scan particular bands of the electromagnetic spectrum to reveal global patterns of temperature, rainfall, or the presence of plants on land or algae in the oceans. The resulting false-color images are both beautiful and filled with vital information.

Plant and Algal Growth These data were gathered by NASA’s Sea-viewing Wide Field-of-view Sensor (SeaWiFS), which is programmed to monitor the color of reflected light. In the image below, you can see how actively plants on land and algae in the oceans were harnessing solar energy for photosynthesis when these data were taken. A measurement of photosynthesis gives a measure of growth rates and the input of energy and nutrients into the ecosystem.

Changes in Polar Ice Cover Sea ice around the North Pole has been melting more each summer since satellites began gathering data in 1979. The image below shows in white the amount of ice remaining at the end of the summer in 2007. The amount of ice at the same time of year for an average year between 1979 and 2007 is shown in green.

On Land Dark green indicates active plant growth; yellow areas indicate barren deserts or mountains.

In the Sea Dark blue indicates very low active growth of algae. Red indicates the highest active growth.

2007 White areas show the average minimum amount of arctic ice cover at the end of the summer, 2007.

1979–2007 Green areas show the average minimum amount of ice cover between 1979 and 2007.

How Science Works

NASA’S EARTH OBSERVING SYSTEM

The National Aeronautics and Space Administration (NASA) program to study Earth is called the Earth Science Enterprise. It includes a series of missions to observe different aspects of Earth and its systems using satellites. Terra, launched in 1999, is considered the “flagship” spacecraft of this program. It collects vast quantities of data about Earth's atmosphere, climate, carbon cycle, water cycle, and weather. Many other missions are a part of the Earth Science Enterprise, including CALIPSO, launched in 2006, which primarily collects data about aerosols and clouds and their relationship to Earth’s climate.

Teach

Lead a Discussion

Have students recall the three methods used in ecological studies.

Ask Would you classify the use of satellite images to study ecology as observation, experimentation, or modeling? Explain your response. (Sample answer: This type of study is observation, because it involves learning about the biosphere by looking at images, rather than experimenting or modeling.)

Ask How could the satellite images be used to develop models? (Sample answer: Scientists might develop a model that shows changes in polar ice cover based on satellite observations made over time.)

Ask How could the satellite images be used to make predictions about future changes on Earth? (Sample answer: Scientists can use these observations to identify trends, allowing them to predict changes that are likely to occur in the future.)

DIFFERENTIATED INSTRUCTION

Advanced Students Have students research the use of platform terrestrial transmitter terminals to track migrating animals. Have them explain how this technology uses satellites to monitor the movement of animals, and describe how ecologists can use the data generated with this technology. Ask students to share what they learned with the class.

Answers

WRITING

Students’ responses will vary, due to the wide variety of satellite images available. Encourage students to explore several sets of images, and to note images with overlays of graphs that can aid in analysis of the images.

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Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab The Effect of Fertilizer on Algae described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Have students be careful when handling cultures and glassware. Protective gloves and goggles should be worn at all times. Make sure students wash hands thoroughly after the lab.

Pre-Lab Answers

BACKGROUND QUESTIONS

a. A limiting nutrient is a chemical substance that is necessary for life whose supply determines the primary productivity of an ecosystem.

b. Most fertilizers contain large amounts of nitrogen, phosphorus, and potassium, which are essential nutrients for plants.

c. Algae are the main photosynthetic producers in freshwater ecosystems. They produce energy-rich compounds that are used by other organisms.

PRE-LAB QUESTIONS

1. The independent variable is the presence of fertilizer.

2. Sample answer: In the test tube with more algae, the liquid will have a darker green color and be less transparent to light.

3. Sample answer: Pond water is likely to contain many species of algae. Using spring water ensures that both test tubes have Chlorella, and that neither test tube has a different algal species.
3 Study Guide

3.1 What Is Ecology?

Ecology is the scientific study of interactions among organisms and between organisms and their physical environment. The biological influences on organisms are called biotic factors. Physical components of an ecosystem are called abiotic factors.

Modern ecologists use three methods in their work: observation, experimentation, and modeling. Each of these approaches relies on scientific methodology to guide inquiry.

3.2 Energy, Producers, and Consumers

Primary producers are the first producers of energy-rich compounds that are later used by other organisms.

Organisms that rely on other organisms for energy and nutrients are called consumers.

3.3 Energy Flow in Ecosystems

Energy flows through an ecosystem in a one-way stream, from primary producers to various consumers. Pyramids of energy show the relative amount of energy available at each trophic level of a food chain or food web. A pyramid of biomass illustrates the relative amount of living organic matter available at each trophic level of an ecosystem. A pyramid of numbers shows the relative number of individual organisms at each trophic level in an ecosystem.

3.4 Cycles of Matter

Unlike the one-way flow of energy, matter is recycled within and between ecosystems. Water continuously moves between the oceans, the atmosphere, and land—sometimes outside living organisms and sometimes inside them.

Every organism needs nutrients to build tissues and carry out life functions. Like water, nutrients pass through organisms and the environment through biogeochemical cycles. The carbon, nitrogen, and phosphorus cycles are especially critical for life.

If ample sunlight and water are available, the primary productivity of an ecosystem may be limited by the availability of nutrients.

Think Visually Using information from this chapter, complete the following flowchart:

3.5 Performance Tasks

SUMMATIVE TASK Have students imagine they are museum curators who have been asked to design an exhibit about the movement of matter and energy in ecosystems. Explain that the exhibit must consist of three separate displays, each of which can be designed in any way they choose. Have them write a paragraph describing each of the three displays they would design. Then, have them write a paragraph summarizing the display as a whole. Have students consider the scientific terms and concepts each display will introduce as they write their descriptions. Encourage them to include sketches or diagrams with their paragraphs.

TRANSFER TASK Have students write a short story from the point of view of a producer in an ecosystem. The story should be at least one page in length and include the following concepts in a creative and scientifically accurate way.

Answers

THINK VISUALLY

1. Autotroph or Primary Producer
2. Carnivore, Omnivore, or Consumer
3. Decomposer or Detritivore

- What interactions occur between the producer and the other living things in the ecosystem?
- What interactions occur between the producer and the nonliving things in the ecosystem?
- What role does the producer serve in the movement of matter and energy in the ecosystem?
Lesson 3.1

UNDERSTAND KEY CONCEPTS
1. c  2. b
3. individual organism, population, community, ecosystem, biome, biosphere
4. Ecologists use modeling to study events that occur over such long periods of time or such large areas that they are difficult to study directly.
5. Sample answer: An adult frog eats insects, therefore, frogs influence the insects in their ecosystem.

THINK CRITICALLY
6. Students’ hypotheses and experimental designs may vary. Experiments should include controls. For example, students might suggest that a set of seeds be divided into two groups—one exposed to high heat and one not exposed to high heat. All other conditions should be kept the same. Then, the germination rates of the two groups can be compared.
7. Students’ questions should indicate they would look for biotic and abiotic factors that might have changed, such as land use around the pond, annual rainfall, and runoff patterns.

Lesson 3.2

UNDERSTAND KEY CONCEPTS
8. c  9. c  10. d
11. Chemosynthesis is a process in which chemical energy is used to produce carbohydrates.

THINK CRITICALLY
12. earthworm, detritivore; bear, omnivore; cow, herbivore; snail, detritivore; owl, carnivore; human, omnivore
13. Sample answer: Organic matter may enter the caves from outside via water or animals that come in from outside. There may also be chemosynthetic bacteria in the cave.

Lesson 3.3

UNDERSTAND KEY CONCEPTS
14. b  15. c

THINK CRITICALLY
16. primary producers
17. Most of the energy organisms consume is used for life processes or released into the environment as heat, which leaves only about 10 percent of the energy available to the next trophic level.

18. Accept all logical food chains that begin with a producer and end with the student.
19. Sample answer: grass, caterpillar, bird, fox; grass, mouse, hawk; grass, mouse, fox; tree, deer, cougar
Lesson 3.4

UNDERSTAND KEY CONCEPTS

20. Nutrients move through an ecosystem in
   a. biogeochemical cycles.
   b. water cycles.
   c. energy pyramids.
   d. phosphorus cycle

21. Which biogeochemical cycle does NOT include a major path in which the substance cycles through the atmosphere?
   a. water cycle
   b. carbon cycle
   c. nitrogen cycle
   d. phosphorus cycle

22. List two ways in which water enters the atmosphere in the water cycle.

23. Explain the process of nitrogen fixation.

24. What is meant by “nutrient limitation”? 

THINK CRITICALLY

25. The fertilizer was carried into the stream by runoff, which prompted the increased growth of algae. The algae disrupted the ecosystem in a way that caused the fish to die.

26. Students’ flowcharts will vary, depending on the organisms included in the food chain. Students’ responses should also include a description of decomposers breaking down the dead organic matter when a top-level carnivore dies, which releases the nitrogen in the carnivore’s body.

After students have read through the Chapter Mystery, discuss interactions of organisms and the environment.

Ask A change in which abiotic factor triggered the series of changes described in the Chapter Mystery? (water temperature)

Ask What is an example of an interaction between two living things in Narragansett Bay that changed as a result of the change in water temperature? (Sample answer: Warm water shrimp now stay in the bay all winter, feeding on baby flounder.)

Ask What is an example of an interaction between a living thing and a nonliving thing that has occurred as a result of the increase in water temperature? (Bacteria in the bay now fix nitrogen, rather than denitrifying the water.)

CHAPTER MYSTERY ANSWERS

1. Many factors have changed in Narragansett Bay. The water temperature has risen, which has allowed bluefish to stay in the bay later in the year than they used to. It has also permitted shrimp to remain in the bay and feed on baby flounder all year round, which likely decreases the flounder population. The late-winter algae bloom no longer occurs, eliminating a food source for the entire ecosystem. Organisms in the bay used to consume nitrogen that flowed into the bay; now the bacteria in the bay fix nitrogen.

2. Sample answer: If the water temperature rises, sea jellies might arrive in the bay earlier in the year and stay later in the fall. They would feed on fish eggs, fish larvae, and zooplankton. If the bay continues to warm, what do you think might happen to the population of sea jellies in the bay? What might that mean for the organisms the jellies feed on?

3. The Narragansett Bay example demonstrates interconnections among members of a food web and abiotic environmental factors. Can you find similar studies in other aquatic habitats, such as Chesapeake Bay, the Everglades, or the Mississippi River delta? Explain.
Connecting Concepts

USE SCIENCE GRAPHICS

27. Productivity increases.

28. Students’ graphs should show productivity leveling out as rainfall increases between 4000 mm and 6000 mm. Student explanations should state that, beyond 4000 mm, something other than rainfall will begin to limit productivity in the ecosystem.

29. Sample answer: amount of sunlight, availability of nutrients

WRITE ABOUT SCIENCE

30. Answers will vary. Students should name and define the levels of organization including individual organism, population, community, ecosystem, biome, and biosphere. Students might choose any of the levels to study. They should describe how their chosen level can be studied using observation, experimentation, or modeling. The reason for the choice of method should be logical and supported in a way that suggests an understanding of that method.

31. Organic compounds, such as proteins, carbohydrates, nucleic acids, and fats, contain elements such as carbon, oxygen, nitrogen, and phosphorus. Atoms of these elements must be available to organisms, or organic compounds cannot be synthesized. The carbon, nitrogen, and phosphorus cycles move these atoms through ecosystems, making them available to living things.

32. Sample answer: Carbon is found in the molecules that make up living things. Therefore, it is a part of the biotic factors in an ecosystem, and moves through the ecosystem in food chains and food webs. Carbon is also present as part of soil and air, and therefore, is an abiotic factor in ecosystems as well.

Think Critically

25. Form a Hypothesis Ecologists discovered that trout were dying in a stream that ran through some farmland where nitrogen fertilizer was used on the crops. How might you explain what happened?

26. Apply Concepts Using a flowchart, trace the flow of energy in a simple marine food chain. Then, show where nitrogen is cycled through the chain when the top-level carnivore dies and is decomposed.

27. Interpret Graphs What happens to productivity as rainfall increases?

28. Predict What do you think the graph would look like if the x-axis were extended out to 6000 mm? Represent your prediction in a graph and explain your answer.

29. Apply Concepts What factors other than water might affect primary productivity?

WRITE ABOUT SCIENCE

30. Explanation Write a paragraph that (1) names and defines the levels of organization that an ecologist studies; (2) identifies the level that you would choose to study if you were an ecologist; (3) describes the method or methods you would use to study this level; and (4) gives a reason for your choice of method or methods.

31. Description Describe how biogeochemical cycles provide organisms with the raw materials necessary to synthesize complex organic compounds. Refer back to Chapter 2 for help in answering this question.

32. Assess the Big idea Explain how an element like carbon can be included in both the biotic and abiotic factors of an ecosystem.

Connecting Concepts

Use Science Graphics

The graph below shows the effect of annual rainfall on the rate of primary productivity in an ecosystem. Use the graph to answer questions 27–29.

[Graph image]

**The Effect of Rainfall on Plant Productivity**

- **Rate of Plant Tissue Production (g/m² per year)**
- **Average Annual Rainfall (mm)**

**Concentration of Oxygen**

<table>
<thead>
<tr>
<th>Depth of Sample (m)</th>
<th>Oxygen Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.5</td>
</tr>
<tr>
<td>50</td>
<td>7.4</td>
</tr>
<tr>
<td>100</td>
<td>7.4</td>
</tr>
<tr>
<td>150</td>
<td>4.5</td>
</tr>
<tr>
<td>200</td>
<td>3.2</td>
</tr>
<tr>
<td>250</td>
<td>3.1</td>
</tr>
<tr>
<td>300</td>
<td>2.9</td>
</tr>
</tbody>
</table>

ANALYZING DATA

Samples of ocean water are taken at different depths, and the amount of oxygen in the water at each depth is measured. The results are shown in the table.

**PURPOSE** Students will analyze data to understand the relationship between the depth of ocean water and its oxygen concentration.

**PLANNING** Explain that the abbreviation ppm means “parts per million,” a unit that is used to express concentration.

**ANSWERS**

33. c

34. The depth to which light can penetrate limits the depths at which photosynthetic organisms can be found. Photosynthetic organisms produce oxygen, so their presence increases oxygen concentrations at the depths where they are found, in this case to about 100 m.
Answers
1. A
2. C
3. D
4. A
5. D
6. A
7. A
8. A
9. Decomposers and detritivores consume matter that does not get passed to the next higher trophic level.

Open-Ended Response
9. What ultimately happens to the bulk of matter in any trophic level of a biomass pyramid—that is, the matter that does not get passed to the trophic level above?
Connect to the Big Idea

Discuss the scene in the photograph to introduce the Big Idea of Interdependence in Nature.

Ask What organisms do you see in the photograph in addition to the cheetah? (plants)

Ask What do you think the cheetah eats and what eats the plants? (zebras or other herbivores)

Ask What would happen to the cheetah if the plants died because of drought? (The herbivores it hunts would have nothing to eat and might die or move to another area, so the cheetah would have no food.)

Lead students to anticipate the answer to the question, How do abiotic and biotic factors shape ecosystems?

After students have read through the Chapter Mystery, ask them to explain why scientists predicted that reintroducing wolves to Yellowstone National Park would lead to a decline in the number of elk in the park. (Wolves hunt elk.) Then, have them predict how fewer elk might affect other organisms in the park. (Sample answer: Elk eat plants, so with fewer elk, there might be more of some types of plants.)

Have students preview the chapter vocabulary using the Flash Cards.

Unifying Concepts and Processes

I, II, III, IV, V

Content


Inquiry

A.1.b, A.1.c, A.1.d, A.2.a, A.2.b, A.2.d

Understanding by Design

Chapter 4 continues to explore the unit’s Enduring Understanding: The existence of life on Earth depends on interactions among organisms and between organisms and their environment. As the graphic organizer at the right shows, the chapter explains how interactions between abiotic factors like climate and biotic factors like organisms shape ecosystems.

Performance Goals

Students will demonstrate their knowledge of ecosystems and communities by analyzing data, interpreting diagrams and graphs, and describing phenomena such as competition and succession. At the end of the chapter, students will create a scrapbook highlighting interactions among organisms and between organisms and their environment in a specific land biome or aquatic ecosystem. They will also create a Web site about a threatened region in a biome and how it can be protected.
THE WOLF EFFECT

During the 1920s, hunting and trapping eliminated wolves from Yellowstone National Park. For decades, ecologists hypothesized that the loss of wolves—important predators of elk and other large grazing animals—had changed the park ecosystem. But because there were no before-and-after data, it was impossible to test that hypothesis directly.

Then, in the mid-1990s, wolves were reintroduced to Yellowstone. Researchers watched park ecosystems carefully and sure enough, the number of elk in parts of the park began to fall just as predicted. But, unpredictably, forest and stream communities have changed, too. Could a “wolf effect” be affecting organisms in the park’s woods and streams?

As you read this chapter, look for connections among Yellowstone’s organisms and their environment. Then, solve the mystery.

Never Stop Exploring Your World.

The mystery of the Yellowstone wolves is just the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

What’s Online

Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY

Students will explore community interactions in Yellowstone National Park since the reintroduction of wolves in the mid-1990s.

UNTAMED SCIENCE VIDEO

A volcanic eruption can quickly obliterate an existing ecosystem, but it also paves the way for a new one to develop.

VISUAL ANALOGY

Students find out how Earth’s atmosphere acts like the glass in a greenhouse.

DATA ANALYSIS

Students analyze tolerance data to explain the zonation patterns of intertidal species.

ART IN MOTION

An animation of primary and secondary succession helps students understand the processes.

ART REVIEW

Students can show an understanding of the ocean’s zones with this drag-and-drop activity.
## Getting Started

### Objectives

**4.1.1 Differentiate** between weather and climate.

**4.1.2 Identify** the factors that influence climate.

### Student Resources

**Study Workbooks A/B, 4.1 Worksheets**

**Spanish Study Workbook, 4.1 Worksheets**

For corresponding lesson in the Foundation Edition, see pages 82–84.

### Answers

**IN YOUR NOTEBOOK** Descriptions will vary depending on the climate where students live. They might describe seasonal variations, amounts of precipitation, and high and low temperatures. They may also identify factors such as distance from the equator and presence of bodies of water or mountain ranges.

## Vocabulary

**PREFIXES** The prefix *hemi-* in *hemisphere* means “half.” The Northern Hemisphere encompasses the northern half of Earth.

## Key Questions

- **What is climate?**
- **What factors determine global climate?**

## Taking Notes

**Preview Visuals** Before you read, look at Figure 4–2. What questions do you have about this diagram? Write a prediction that relates this figure to climate.

## Weather and Climate

**What is climate?**

Weather and climate both involve variations in temperature, precipitation, and other environmental factors. **Weather** is the day-to-day condition of Earth's atmosphere. Weather where you live may be clear and sunny one day but rainy and cold the next. **Climate**, on the other hand, refers to average conditions over long periods. A region's climate is defined by year-after-year patterns of temperature and precipitation.

It is important to note that climate is rarely uniform even within a region. Environmental conditions can vary over small distances, creating microclimates. For example, in the Northern Hemisphere, south-facing sides of trees and buildings receive more sunlight, and are often warmer and drier, than north-facing sides. We may not notice these differences, but they can be very important to many organisms.

### Factors That Affect Climate

**What factors determine global climate?**

A person living in Orlando, Florida, may wear shorts and a T-shirt in December, while someone in Minneapolis, Minnesota, is still wearing a heavy coat in April. It rarely rains in Phoenix, Arizona, but it rains often in Mobile, Alabama. Clearly, these places all have different climates—but why? What causes differences in climate? **Global climate** is shaped by many factors, including solar energy trapped in the biosphere, latitude, and the transport of heat by winds and ocean currents.

**In Your Notebook** Describe the climate where you live. What factors influence it?
Solar Energy and the Greenhouse Effect

The main force that shapes our climate is solar energy that arrives as sunlight and strikes Earth’s surface. Some of that energy is reflected back into space, and some is absorbed and converted into heat. Some of that heat, in turn, radiates back into space, and some is trapped in the biosphere. The balance between heat that stays in the biosphere and heat lost to space determines Earth’s average temperature. This balance is largely controlled by concentrations of three gases found in the atmosphere—carbon dioxide, methane, and water vapor.

As shown in Figure 4–1, these gases, called greenhouse gases, function like glass in a greenhouse, allowing visible light to enter but trapping heat. This phenomenon is called the greenhouse effect. If greenhouse gas concentrations rise, they trap more heat, so Earth warms. If their concentrations fall, more heat escapes, and Earth cools. Without the greenhouse effect, Earth would be about 30°C cooler than it is today. Note that all three of these gases pass in and out of the atmosphere as part of nutrient cycles.

Latitude and Solar Energy

Near the equator, solar energy is intense as the sun is almost directly overhead at noon all year. That’s why equatorial regions are generally so warm. As Figure 4–2 shows, the curvature of Earth causes the same amount of solar energy to spread out over a much larger area near the poles than near the equator. Thus, Earth’s polar areas annually receive less intense solar energy, and therefore heat, from the sun. This difference in heat distribution creates three different climate zones: tropical, temperate, and polar.

The tropical zone, or tropics, which includes the equator, is located between 23.5° north and 23.5° south latitudes. This zone receives nearly direct sunlight all year. On either side of the tropical zone are the two temperate zones, between 23.5° and 66.5° north and south latitudes. Beyond the temperate zones are the polar zones, between 66.5° and 90° north and south latitudes. Temperate and polar zones receive very different amounts of solar energy at different times of the year because Earth’s axis is tilted. As Earth revolves around the sun, solar radiation strikes different regions at angles that vary from summer to winter. During winter in the temperate and polar zones, the sun is much lower in the sky, days are shorter, and solar energy is less intense.

Biology In-Depth

CLIMATE CHANGE AND EARTH’S ORGANISMS

While human actions only enhance the natural greenhouse effect, even a small change in its intensity can cause great disruption in ecosystems worldwide. Not only will global temperatures rise, but an enhanced greenhouse effect can change the precipitation and other weather patterns that are fueled by the temperature differential between equatorial and polar regions. At the current rate of global warming, some of Earth’s present climates may disappear and be replaced by different climates over the next century. Many scientists predict these changes to be most pronounced in tropical and subtropical regions. As climates change, so will Earth’s organisms. There is already evidence that the ranges of some species, including certain butterflies, are shifting toward the poles. Many other species, which will be unable to move to new areas when climates change, are likely to go extinct.

Teach

Use Models

Have students model the relationship between latitude and solar energy with a globe and flashlight. Ask one student to hold the globe in the same position as the drawing of Earth in Figure 4–2. Ask another student to shine the flashlight straight ahead onto northern North America. Ask the class to observe the size of the area that is receiving light. Then, have the student shine the flashlight straight ahead onto the equator. Point out how a smaller area is now receiving the same amount of light.

DIFFERENTIATED INSTRUCTION

Advanced Students

Point out that the “beams” of sunlight shown in Figure 4–2 create different shapes when they hit Earth at different angles—a circle near the equator and an ellipse near the poles. Demonstrate mathematically the difference between the areas of light received at these locations. Use an overhead projector and a piece of paper with a circular cutout to project a circle of light onto a piece of cardboard. Have students trace the shape of the projected circle of light onto the cardboard when it is upright. Then, have them tilt the cardboard 45 degrees back so that the light forms an ellipse. Have students trace this shape. Next, have them measure the lengths of the radius (r) of the circle and the semi-major (r₁) and semi-minor (r₂) axes of the ellipse. Finally, have them compare the areas of the two shapes using these formulas:

Area of a circle = πr²
Area of an ellipse = π(r₁)(r₂)

Answers

FIGURE 4–1 the glass
Assess and RemEDIATE

EVALUATE UNDERSTANDING

Call on students at random to identify factors that influence climate. Call on other students to explain how each factor affects climate. Then, have students complete the 4.1 Assessment.

REMEDICATION SUGGESTION

**Struggling Students** If students have trouble answering **Question 1c**, give them the background information they need to infer the answer. Explain that air is under less pressure at the top of mountains, so its molecules spread out. When the molecules of a gas spread out, the gas loses heat.

Students can check their understanding of lesson concepts with the **Self-Test** assessment. They can then take an online version of the **Lesson Assessment**.

**FIGURE 4–3** Cold currents in the Northern Hemisphere generally move southward, away from the North Pole and toward the equator.

**Assessment Answers**

1a. Climate is the average conditions of a location and is defined by year-after-year temperature and precipitation patterns.

1b. Weather is the day-to-day condition of Earth’s atmosphere, whereas climate refers to average conditions over long periods.

1c. The figure shows cold surface currents moving up along the western coast and warm surface currents moving down the eastern coast; this pattern suggests that the west coast of southern Africa has a cooler climate.

2a. Climate is determined by solar energy trapped in the biosphere, latitude, and the transport of heat by winds and ocean currents.

2b. A decrease in greenhouse gases would allow more reradiated heat to escape to space, rather than being absorbed by the atmosphere, so global climate would become cooler.

3. Graphs should show that average monthly temperatures are very similar from month to month for the entire year, with an average temperature of about $15^\circ$C. Precipitation is much more variable. It is low from June through September and high from October through May, ranging from about 25 mm on average for the driest month to about 175 mm on average for the wettest month.
NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES
I, II, III

CONTENT
C.4.b, C.4.c, C.4.d, C.5.e

INQUIRY
A.1.c, A.2.a, A.2.d
Lead a Discussion

Work with students to apply the concepts of habitat and niche to organisms they are familiar with. On the board, write the names of several organisms. Choose a wide range of organisms, such as pine trees, dandelions, raccoons, frogs, and butterflies. Call on students to identify factors that help determine each organism’s habitat or describe its niche. Use the exercise to reinforce the differences between habitat and niche and to clarify that niche is a property of organisms, not ecosystems.

DIFFERENTIATED INSTRUCTION

□ Struggling Students Give students an analogy to help them understand the concept of niche. Tell them that an animal’s niche is like the position an athlete plays in a team sport. Ask a student to name a player position for their favorite sport. Then, explain how this position is like a niche. For example, discuss the role a player in a given position fulfills for the team, the physical space the player occupies, and how the player interacts with fellow teammates and competitors.

□ Focus on ELL: Extend Language

ALL SPEAKERS Ask students to write each of the lesson vocabulary terms on an index card. Then, have them divide each term into parts and read the sentence in which it is highlighted in the text. Tell beginning and intermediate speakers to write a phrase explaining what they think each term means and to make a drawing to illustrate it. Use examples to give them a clearer idea of any terms they do not understand. Instruct advanced and advanced high speakers to write the definition of each term based on its context in the paragraph where it is introduced. Review their definitions and correct any misunderstandings they might have.

Answers

FIGURE 4–5 Sample answer: I think they are fighting over food, living space, mates, or a place to raise their young.

IN YOUR NOTEBOOK It is probably an example of intraspecific competition, because both beetles appear to belong to the same species.

Defining the Niche Describing a species’ “address” tells only part of its story. Ecologists also study a species’ ecological “occupation”—where and how it “makes a living.” This idea of occupation is encompassed in the idea of an organism’s niche (niche). A niche describes not only what an organism does, but also how it interacts with biotic and abiotic factors in the environment. A niche is the range of physical and biological conditions in which a species lives and the way the species obtains what it needs to survive and reproduce.

Understanding niches is important to understanding how organisms interact to form a community.

Resources and the Niche The term resource can refer to any necessity of life, such as water, nutrients, light, food, or space. For plants, resources can include sunlight, water, and soil nutrients—all of which are essential to survival. For animals, resources can include nesting space, shelter, types of food, and places to feed.

Physical Aspects of the Niche Part of an organism’s niche involves the abiotic factors it requires for survival. For example, lose and absorb water through their skin, so they must live in moist places. If an area is too hot and dry, or too cold for too long, most amphibians cannot survive.

Biological Aspects of the Niche Biological aspects of an organism’s niche involve the biotic factors it requires for survival. When and how it reproduces, the food it eats, and the way in which it obtains that food are all examples of biological aspects of an organism’s niche. Birds on Christmas Island, a small island in the Indian Ocean, for example, all live in the same habitat but they prey on fish of different sizes and feed in different places. Thus, each species occupies a distinct niche.

Competitive Exclusion Principle

The competitive exclusion principle was first introduced by Russian ecologist G.F. Gause in the 1930s. His laboratory experiments with paramecia are described in the text on page 101. When Gause cultured two closely related paramecium species together, one species was less able to resist the toxic wastes that built up in the culture, and that species died out. Subsequent research has shown that Gause’s principle applies only when two species have identical niches. If there are slight differences in their niches, two competing species may coexist. This has been demonstrated in many plant and animal species. In some cases, the competing species may prefer different microhabitats. In other cases, each species may do better at different times in a fluctuating environment.
**The Competitive Exclusion Principle** Direct competition between different species almost always produces a winner and a loser—and the losing species dies out. One series of experiments demonstrated this using two species of single-celled organisms. When the species were grown in separate cultures under the same conditions, each survived, as shown in Figure 4–6. But when both species were grown together in the same culture, one species outcompeted the other. The less competitive species did not survive.

Experiments like this one, along with observations in nature, led to the discovery of an important ecological rule. The competitive exclusion principle states that no two species can occupy exactly the same niche in exactly the same habitat at exactly the same time. If two species attempt to occupy the same niche, one species will be better at competing for limited resources and will eventually exclude the other species. As a result, if we look at natural communities, we rarely find species whose niches overlap significantly.

**Dividing Resources** Instead of competing for similar resources, species usually divide them. For instance, the three species of North American warblers shown in Figure 4–7 all live in the same trees and feed on insects. But one species feeds on high branches, another feeds on low branches, and another feeds in the middle. The resources utilized by these species are similar yet different. Therefore, each species has its own niche. This division of resources was likely brought about by past competition among the birds. By causing species to divide resources, competition helps determine the number and kinds of species in a community and the niche each species occupies.

**Check for Understanding**

**ONE-MINUTE RESPONSE**

Ask students to write a one-minute response explaining how competition for some, but not all, resources defines the different niches that two competing species occupy. (The two species must divide or compete for only some of the resources that are available in a habitat. If they competed for all of the same exact resources, then the competitive exclusion principle would predict that one species would eventually die out. Both the resources that they compete for and the resources that they do not have to compete with one another for determine the species’ niches.)

**ADJUST INSTRUCTION**

Collect and review students’ responses. Read aloud a few of the accurate explanations and also any that reveal misunderstandings. Call on volunteers to identify and correct the misunderstandings.

**Lead a Discussion**

Point out the fighting beetles in Figure 4–5, and state that this is only one way in which competition occurs. In fact, competition often occurs without direct physical conflict. Discuss familiar examples, such as the competition for light and nutrients between weeds and tomato plants in a garden. To generate more examples, show students pictures of different ecosystems and ask them to identify resources that are needed by more than one type of organism. (Examples of resources might include water and space.) Then, discuss how the organisms pictured compete for these resources.

**DIFFERENTIATED INSTRUCTION**

**LPR Less Proficient Readers** Help students understand the difference between intraspecific and interspecific competition. Tell them that *intra-* means “within” and *inter-* means “between.” Have students look up the meanings of the following pairs of words: intramural and intermural, intrastate and interstate, and intraspecies and interspecies. Have them draw pictures to distinguish between the definitions of each word pair. As a class, write sentences for each word that provide contextual meaning.

**L Advanced Students** Tell students that a technical term for competing species dividing similar resources within a habitat is *niche partitioning*. Have them look up the word *partition* and describe in their own words what *niche partitioning* means.

**Answers**

**FIGURE 4–7** One species would be better at competing for food in that niche and would eventually exclude the other species.
**Teach continued**

**Lead a Discussion**

If you ask students to name predators and herbivores, they are likely to mention mammals such as wolves and deer. Widen their perspective by discussing examples of the more prevalent yet often less familiar predators and herbivores of the insect world. Tell students that insect herbivores, such as beetles and caterpillars, destroy large numbers of crops worldwide, and insect predators, such as ladybeetles and lacewings, eat many of these crop pests. Ask students to predict how the use of chemical pesticides to kill insect herbivores might affect insect predators. *(Sample answer: The pesticides might kill both types of insects. Then, if insect herbivores increase in numbers again, there might not be enough predators left to control them.)*

**DIFFERENTIATED INSTRUCTION**

**ELL** English Language Learners Tell students that the word *prey* is both a noun and a verb. Have students write sentences using each form of the word. Then, explain that, as a noun, it is an uncountable word, which means it cannot be plural or described using numbers. Compare the word *prey* to another uncountable noun, such as *information*, and as a class come up with sentences that demonstrate how these words do not have a plural form.

**EL** Advanced Students Encourage students to research defenses that have evolved in organisms as protection against predators and herbivores. Such defenses might include camouflage, quills or thorns, toxins, warning coloration, or mimicry. Have students share their findings with the class in oral reports, posters, or displays.

**PurPOSE** Students will interpret an idealized computer model to infer relationships between predator and prey populations.

**PLANNING** Before students answer the questions, discuss why there is a time lag between the predator and prey population changes shown in the graph.

**ANSWERS**

1. If most of the prey were killed off at point B, the predator population would decline between points B and C, allowing the prey population to increase again by point C.

2. The prey population would increase in the next cycle, reaching a peak that is potentially even higher than the previous peaks.

3. Sample answer: If a viral infection kills all the prey at point D, at point E, the prey population will be zero and the predator population would be decreased, possibly to zero. In future years, if the predators find another food resource, the population may recover. The predator population would not recover in future years without any prey to feed on. To ensure continued survival of the predators in this ecosystem, ecologists could control the viral infection in the prey so that not all of them are killed by the virus, or they could introduce new prey animals to the ecosystem.

**Analyzing Data**

**Predation, Herbivory, and Keystone Species**

- How do predation and herbivory shape communities?
- Virtually all animals, because they are not primary producers, must eat other organisms to obtain energy and nutrients. Yet if a group of animals devours all available food in the area, they will no longer have anything to eat! That’s why predator-prey and herbivore-plant interactions are very important in shaping communities.

**Predator-Prey Relationships** An interaction in which one animal (the predator) captures and feeds on another animal (the prey) is called predation *(pree DAY shun)*. **Predators can affect the size of prey populations in a community and determine the places prey can live and feed.** Birds of prey, for example, can play an important role in regulating the population sizes of mice, voles, and other small mammals.

**Herbivore-Plant Relationships** Interactions between herbivores and plants, like the one shown in Figure 4–8, are as important as interactions between predators and prey. An interaction in which one animal (the herbivore) feeds on producers (such as plants) is called herbivory. **Herbivores can affect both the size and distribution of plant populations in a community and determine the places that certain plants can survive and grow.** Herbivores ranging from caterpillars to elk can have major effects on plant survival. For example, very dense populations of white-tailed deer are eliminating their favorite food plants from many places across the United States.

**Figure 4–8 Herbivory** The ring-tailed lemur is an herbivore—meaning that it obtains its energy and nutrients from plants like the cactus it’s eating here.
Keystone Species Sometimes changes in the population of a single species, often called a **keystone species**, can cause dramatic changes in the structure of a community. In the cold waters off the Pacific coast of North America, for example, sea otters devour large quantities of sea urchins. Urchins, in turn, are herbivores. Their favorite food is kelp, giant algae that grow in undersea “forests.”

A century ago, sea otters were nearly eliminated by hunting. Unexpectedly, the kelp forest nearly vanished. What happened? Without otters as predators, the sea urchin population skyrocketed. Without kelp to provide habitat, many other animals, including seabirds, disappeared. Clearly, otters were a keystone species in this community. After otters were protected as an endangered species, their population began to recover. As otters returned, the urchin populations dropped, and kelp forests began to thrive again. Recently, however, the otter population has been falling again, and no one knows why.

**In Your Notebook** Not all keystone-species effects are due to predation. Describe the dramatic effects that the dam-building activities of beavers, a keystone species, might have on other types of organisms.

Symbioses

What are the three primary ways that organisms depend on each other?

Any relationship in which two species live closely together is called **symbiosis**, (sim by oh siis), which means “living together.” Biologists recognize three main classes of symbiotic relationships in nature: **mutualism**, **parasitism**, and **commensalism**.

**Mutualism** The sea anemone’s sting has two functions: to capture prey and to protect the anemone from predators. Even so, certain fish manage to snack on anemone tentacles. The clownfish, however, is immune to anemone stings. When threatened by a predator, clownfish seek shelter by snuggling deep into tentacles that would be deadly to most other fish, as seen in Figure 4–9. But if an anemone-eating species tries to attack their living home, the spunky clownfish dart out and fiercely chase away fish many times their size. This kind of relationship between species in which both benefit is known as **mutualism**.

**FIGURE 4–9 Mutualism** Clownfish live among the sea anemone’s tentacles and protect the sea anemone by chasing away would-be attackers. The sea anemone, in turn, protects the clownfish from their predators. Infer: What could happen to the sea anemone if the clownfish died?

Use Visuals

Use Figure 4–9, Figure 4–10, and Figure 4–11 to introduce the three main classes of symbiotic relationships. For each figure, call on students to identify the two organisms that are involved in the relationship and how they interact. Describe several additional examples of symbiotic relationships, and ask students to identify the class of relationship each example represents. Examples might include flowering plants and their insect pollinators (mutualism); mistletoe and its plant hosts, trees and shrubs (parasitism); and burdock plants and animals with fur that transport their seeds (commensalism). Choose one example of each type of relationship. Then, for each example, discuss with the class how a change in numbers of one species in the relationship might affect numbers of the other species.

DIFFERENTIATED INSTRUCTION

**ELL** English Language Learners Suggest students fill in a **Compare/Contrast Table** on symbiosis as they read about it in the lesson. Their tables should have a row for each of the three main classes of symbiotic relationships. Columns should address which of the organisms benefit from the relationship and provide examples.

**Study Wkbks A/B, Appendix S20, Compare/Contrast Table. Transparencies, GO3.**

**Mystery Clue** Remind students that elk are herbivores. Have them reread the paragraph with the blue heading, Herbivore-Plant Relationships, to help them answer the question. Students are likely to respond that a declining elk population due to wolf predation would give certain plants a better chance of growing, because fewer of them would be eaten by elk. Students can go online to Biology.com to gather their evidence.

**Answers**

**FIGURE 4–9** The sea anemone might be killed by predators if the clownfish died.

**In Your Notebook** Sample answer: Dam building might flood land upstream from the dam and reduce the flow of water downstream from the dam. Land organisms living upstream might die out because their habitats are flooded, and aquatic organisms living downstream might die out because their habitats dry up. Beavers also might destroy most of the trees near the water’s edge to build their dams, and this could increase runoff and erosion, which could change the habitat of species that rely on soil.

Quick Facts

**THE HUMAN SUPERORGANISM**

Humans and the bacteria that live in and on the human body are involved in numerous symbiotic relationships—many of them **mutualistic**. An example of one mutualistic human-bacterial relationship involves certain bacteria on the skin that process fats produced by the skin and help keep the skin moist. This is just one of an estimated 20 or more different niches of bacteria on the human skin alone. Other mutualistic relationships involve bacteria in the gut, which feast on the products of digestion while helping to break down carbohydrates. Because of the important roles bacteria play in the human animal and the huge numbers of bacteria that inhabit the human body, some microbiologists think that each person should be thought of as a superorganism, composed of one human and trillions of bacteria.
LESSON 4.2

Assess and Remediate

EVALUATE UNDERSTANDING

On the board, list the six types of community interactions described in the lesson (competition, predation, herbivory, mutualism, parasitism, and commensalism). For each interaction, call on a student to give a definition and another student to give an example. Then, have students complete the 4.2 Assessment.

REMEDIATION SUGGESTION

Struggling Students If students have trouble with Question 4c, tell them to think about what happens to people when they are bitten by parasites such as mosquitos.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. A habitat is the general place where an organism lives. A niche also describes how the organism interacts with its environment.

1b. A profession is the role a person plays in his or her community. Like a profession, a niche is the role an organism plays in its community. Students should describe the physical and biological aspects of their own niche.

2a. Competition is an interaction between organisms in which both organisms attempt to use the same limited ecological resource in the same place at the same time. Two organisms that live in different habitats can’t compete because they do not live in the same place.

2b. All three warbler species live in the same trees and feed on insects, but each species has its own niche because it uses resources in a different part of the tree.

3a. A keystone species is a species that causes dramatic changes in the structure of a community if its population changes.

3b. A decrease in vegetation could reduce the number of herbivores. With fewer herbivores, there would be less food for predators, so the predators might decrease in numbers, as well.

4a. Symbiosis is any relationship in which two species live closely together. The three major types of symbiosis are mutualism, parasitism, and commensalism.

4b. This is an example of mutualism, because both the cow and the bacteria benefit from the relationship.

4c. A predator usually kills its prey. A parasite generally only weakens its host.

BUILD VOCABULARY

5. Mutual means “shared, or in common,” so mutualism can be defined as “the act of sharing in common.”
Do you enjoy being outdoors? If you do, you might want to consider one of these careers.

**MARINE BIOLOGIST**
Ocean ecosystems cover over 70 percent of Earth’s surface. Marine biologists study the incredible diversity of ocean life. Some marine biologists study organisms found in deep ocean trenches to understand how they survive in extreme conditions. Others work in aquariums, where they might conduct research, educate the public, or rehabilitate rescued marine wildlife.

**PARK RANGER**
For some people, camping and hiking aren’t just recreational activities—they’re work. Park rangers work in national, state, and local parks caring for the land and ensuring the safety of visitors. Park rangers perform a variety of tasks, including maintaining campsites and helping with search and rescue. Rangers are also responsible for looking after park wildlife.

**WILDLIFE PHOTOGRAPHER**
Wildlife photographers capture nature “in action.” Their photographs can be used in books, magazines, and on the Internet to educate and entertain the public. Successful wildlife photographers need to be observant and adventurous. They also need to be patient enough to wait for the perfect shot.

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**CAREER CLOSE-UP**

**Dudley Edmondson, Wildlife Photographer**
Dudley Edmondson began bird-watching at a young age. After high school, he began traveling and photographing the birds he observed. Mr. Edmondson has since been all over the United States taking pictures of everything from the landscapes and grizzly bears of Yellowstone Park to the butterflies that inhabit his own backyard. Through his work, he hopes to inspire people to travel and experience nature for themselves. This, he believes, will encourage a sense of responsibility to protect and preserve the environment.

“**What I like most about my work is the unique perspective it gives me on the world. Birds, insects, and plants are totally unaware of things like clocks, deadlines, and technology. When you work with living things, you work on their terms.**”

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**Answers**

**WRITING** Sample answer: I have seen nature photography on television shows and in nature magazines and science textbooks. The photos help the public learn about the diversity of life by showing how different organisms look and behave in their natural environment.

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**DIFFERENTIATED INSTRUCTION**

**LPR** Less Proficient Readers  Before students read about the careers described on this page, have them write a question they would like to have answered about each career. Tell them to try to find the answer to their question as they read. If any of their questions remain unanswered, discuss how they could find the answers. Encourage them to follow their plan to locate the information.

**L3** Advanced Students  Ask interested students to learn more about one of the biology careers described on this page. Then, have them write a short, fictionalized account, based on what they learn, in which they describe a typical workday for a person in that career. Ask students to share their accounts with the class.

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**Quick Facts**

**THE BEST OF BOTH FIELDS**
Some people have more than one career at the same time or multiple careers in sequence. One example is Ron Austing, who pursued his love of nature by becoming both a park ranger and a wildlife photographer. Although he is now retired from his job as wildlife manager of a 16,000-acre park, Austing is still active as a wildlife photographer. His nature photographs have appeared in numerous publications, including *National Geographic*, *Audubon*, *National Wildlife*, *Sports Illustrated*, and many books. Like Dudley Edmondson, Ron Austing especially enjoys taking photographs of birds.
Getting Started

Objectives

4.3.1 Describe how ecosystems recover from a disturbance.

4.3.2 Compare succession after a natural disturbance with succession after a human-caused disturbance.

Student Resources

Study Workbooks A/B, 4.3 Worksheets
Spanish Study Workbook, 4.3 Worksheets

Build Background

Describe or show photographs of a local area, familiar to students, that was recently disturbed by a natural event or human actions. Ask students to predict how the area would look in ten years if it were left undisturbed. Tell them they will learn what happens to such disturbed areas in this lesson.

Have students watch animations of succession in Art in Motion: Primary and Secondary Succession.

THINK ABOUT IT

In 1883, the volcanic island of Krakatau in the Indian Ocean was blown to pieces by an eruption. The tiny island that remained was completely barren. Within two years, grasses were growing. Fourteen years later, there were 49 plant species, along with lizards, birds, bats, and insects. By 1929, a forest containing 300 plant species had grown. Today, the island is blanketed by mature rain forest. How did the island ecosystem recover so quickly?

Primary and Secondary Succession

How do communities change over time?

The story of Krakatau after the eruption is an example of ecological succession—a series of more-or-less predictable changes that occur in a community over time. Ecosystems change over time, especially after disturbances, as some species die out and new species move in. Over the course of succession, the number of different species present typically increases.

Primary Succession

Volcanic explosions like the ones that destroyed Krakatau in 1883 and blew the top off Mount Saint Helens in Washington State in 1980 can create new land or sterilize existing areas. Retreating glaciers can have the same effect, leaving only exposed bare rock behind them. Succession that begins in an area with no remnants of an older community is called primary succession. An example of primary succession is shown in Figure 4–12.

Key Questions

- How do communities change over time?
- Do ecosystems return to "normal" following a disturbance?

Vocabulary

ecological succession
primary succession
pioneer species
secondary succession

Taking Notes

Compare/Contrast Table
As you read, create a table comparing primary and secondary succession.

FIGURE 4–12 Primary Succession

Primary succession occurs on newly exposed surfaces. In Glacier Bay, Alaska, a retreating glacier exposed barren rock. Over the course of more than 100 years, a series of changes has led to the hemlock and spruce forest currently found in the area. Changes in this community will continue for centuries.

ENDURING UNDERSTANDING

The existence of life on Earth depends on interactions among organisms and between organisms and their environment.

GUIDING QUESTION

How do ecosystems change over time?

EVIDENCE OF UNDERSTANDING

After completing the lesson, assign students the following assessment to show they understand how succession changes ecosystems over time. Tell students to use the information from the lesson to write a short story about an ecosystem that is disturbed and undergoes either primary or secondary succession. Remind them to write about both biotic and abiotic factors.
The first species to colonize barren areas are called **pioneer species**—named after rugged human pioneers who first settled the wilderness. After pioneers created settlements, different kinds of people with varied skills and living requirements moved into the area. Pioneer species function in similar ways. One ecological pioneer that grows on bare rock is lichen—a mutualistic symbiosis between a fungus and an alga. Over time, lichens convert, or fix, atmospheric nitrogen into useful forms for other organisms, break down rock, and add organic material to form soil. Certain grasses, like those that colonized Krakatau early on, are also pioneer species.

**Secondary Succession** Sometimes, existing communities are not completely destroyed by disturbances. In these situations, where a disturbance affects the community without completely destroying it, **secondary succession** occurs. Secondary succession proceeds faster than primary succession, in part because soil survives the disturbance. As a result, new and surviving vegetation can regrow rapidly. Secondary succession often follows a wildfire, hurricane, or other natural disturbance. We think of these events as disasters, but many species are adapted to them. Although forest fires kill some trees, for example, other trees are spared, and fire can stimulate their seeds to germinate. Secondary succession can also follow human activities like logging and farming. An example of secondary succession is shown in Figure 4–13.

**Why Succession Occurs** Every organism changes the environment it lives in. One model of succession suggests that as one species alters its environment, other species find it easier to compete for resources and survive. As lichens add organic matter and form soil, for example, mosses and other plants can colonize and grow. As organic matter continues to accumulate, other species move in and change the environment further. For example, as trees grow, their branches and leaves produce shade and cooler temperatures nearer the ground. Over time, more and more species can find suitable niches and survive.

**In Your Notebook** Summarize what happens in primary and secondary succession.

**Vocabulary**

**BUILD Vocabulary**

**WORD ORIGINS** The origin of the word succession is the Latin word succedere, meaning “to come after.” **Ecological succession** involves changes that occur one after the other as species move into and out of a community.

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**Teach**

**Use Visuals**

Guide students in using Figures 4–12 and 4–13 to compare and contrast primary and secondary succession.

**Ask** How are the two areas different when succession first begins? (The area in Figure 4–12 is nothing but bare rock and some lichen. The area in Figure 4–13 already has soil and a few small plants.)

**Ask** How long does it take for young trees to grow in each case? (35 to 80 years for primary succession, and 3 to 5 years for secondary succession)

**DIFFERENTIATED INSTRUCTION**

**LPR** Less Proficient Readers Have students make a Flowchart to show the sequence of events that typically occurs during primary succession. Each stage in their flowchart should include a description of that stage and an approximate number of years since the start of succession. Make sure students realize that succession does not always proceed in exactly the same way and that it is a continuous process.

**Study Wkbks A/B, Appendix S25, Flowchart. Transparencies, GO8.**

**ELL** Focus on ELL: Build Background

**ADVANCED AND ADVANCED HIGH SPEAKERS**

Read a description of the aftermath of the volcanic eruption on Krakatau in 1883. As you read, have students draw a sketch of what you are describing. Encourage them to discuss the description. Then, ask them to fill in column B of a **BKWL Chart** with background from the discussion. Tell them to list anything they can infer about succession after a volcanic explosion in column K and questions they have about it in column W. After students read the lesson, have them complete column L and describe what they have learned.

**Study Wkbks A/B, Appendix S27, BKWL Chart. Transparencies, GO12.**

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**Answers**

**IN YOUR NOTEBOOK** Primary succession occurs in areas with no previous community. After pioneer species move in and help form soil, other species gradually colonize. Secondary succession occurs when a community is disturbed but soil remains. Surviving vegetation regrows, and new vegetation moves in.

**Ecosystems and Communities 107**
LESSON 4.3

Lead a Discussion

Help students understand how ideas about succession have changed over the years.

Ask How have ecologists’ ideas about climax communities changed? (Formerly, they thought that the stages of succession were always the same and that stable climax communities were always the end result.)

Ask What types of information changed their thinking? (Climax communities resulting from multiple disturbances were more like patchwork quilts than the original climax community.)

Differentiated Instruction

Struggling Students  Help students understand how climax communities can be unstable. Provide students with visuals of regrowth after a forest fire or lava flow. Then, have them compare these examples with images of the growth of weeds or trees through concrete or asphalt. Ask them to infer why the plants that appear after the forest fire or lava flow are more likely to reach maturity and provide niches for other species than the plants that appear after an area is paved by humans. Compare the periodic maintenance of a road to an area in nature that undergoes frequent disturbances. In both situations the resulting climax community is not stable.

Answers

FIGURE 4–14  Secondary succession occurred, since soil and a few plants remained in the area after the storm.

IN YOUR NOTEBOOK  Instability in some climax communities is caused by frequent disturbances.

Quick Lab

PURPOSE  Students will conclude whether ecological succession has occurred in a closed aquatic community.

MATERIALS  dried plant material, jar with lid, boiled pond water or sterile spring water, pH paper, microscope, slides, coverslips, pipette

SAFETY  Remind students to handle the slides and pipette carefully and to wash their hands thoroughly after completing the lab.

PLANNING  Obtain aquatic plants from a pet or aquarium store and spread them out to dry on baking sheets for a few days. Quart-sized canning jars are a good choice for the lab. You can sterilize them by filling them with boiling water and letting them air dry.

ANALYZE AND CONCLUDE

1. I used boiled water to avoid introducing organisms with the water added to the jar.
2. The organisms came from the dried plant material.
3. Sample answer: Yes, ecological succession was occurring, because the habitat inside the jar was changed by the living things in the jar. Tiny organisms grew in the water, turning it cloudy.

4. Sample answer: We all had organisms growing in the water in our jars, but we observed different numbers and types of organisms. The differences could be due to chance. There may have been different types of organisms in the dried plant material we started with, or we may have sampled different organisms when we prepared the slides.

Climax Communities

Do ecosystems return to “normal” following a disturbance?

Ecologists used to think that succession in a given area always proceeds through the same stages to produce a specific and stable climax community like the mature spruce and hemlock forest that is developing in Glacier Bay. Recent studies, however, have shown that succession doesn’t always follow the same path, and that climax communities are not always uniform and stable.

Succession After Natural Disturbances  Natural disturbances are common in many communities. Healthy coral reefs and tropical rain forests recover from storms, as shown in Figure 4–14. Healthy temperate forests and grasslands recover from wildfires. Secondary succession in healthy ecosystems following natural disturbances often reproduces the original climax community. But detailed studies show that some climax communities are not uniform. Often, they look more like patchwork quilts with areas in varying stages of secondary succession following multiple disturbances that took place at different times. Some climax communities are disturbed so often that they can’t really be called stable.

In Your Notebook  Describe what causes instability in some climax communities.

FIGURE 4–14 Recovery From a Natural Disaster  These photos show El Yunque Rain Forest in Puerto Rico, immediately following Tropical Storm Jeanne in September 2004, and then again in May, 2007.

Apply Concepts  What kind of succession occurred in this rain forest? How do you know?

Answers

FIGURE 4–14 Recovery From a Natural Disaster  These photos show El Yunque Rain Forest in Puerto Rico, immediately following Tropical Storm Jeanne in September 2004, and then again in May, 2007.

Show El Yunque Rain Forest in Puerto Rico, immediately following Tropical Storm Jeanne in September 2004, and then again in May, 2007.

Successful Succession?  

1. Place a handful of dried plant material into a clean jar.
2. Fill the jar with boiled pond water or sterile spring water. Determine the initial pH of the water with pH paper.
3. Cover the jar and place it in an area that receives indirect light.
4. Examine the jar every day for the next few days.
5. When the water in the jar appears cloudy, prepare microscope slides of water from various levels of the jar. Use a pipette to collect the samples.

Look at the slides under the low-power objective lens of a microscope and record your observations.

Analyze and Conclude

1. Infer  Why did you use boiled or sterile water?
2. Infer  Where did the organisms you saw come from?
3. Draw Conclusions  Was ecological succession occurring? Give evidence to support your answer.
4. Evaluate and Revise  Check your results against those of your classmates. Do they agree? How do you explain any differences?
Succession After Human-Caused Disturbances  In North America, land cleared for farming and then abandoned often passes through succession that restores the original climax community. But this is not always the case. Ecological systems may or may not recover from extensive human-caused disturbances. Clearing and farming of tropical rain forests, for example, can change the microclimate and soil enough to prevent regrowth of the original community.

Studying Patterns of Succession  Ecologists, like the ones seen in Figure 4–15, study succession by comparing different cases and looking for similarities and differences. Researchers who swarmed over Mount Saint Helens as soon as it was safe might also have studied Krakatau, for example. In both places, primary succession proceeded through predictable stages. The first plants and animals that arrived had seeds, spores, or adult stages that traveled over long distances. Hardy pioneer species helped stabilize loose volcanic debris, enabling later species to take hold. Historical studies in Krakatau and ongoing studies on Mount Saint Helens confirm that early stages of primary succession are slow, and that chance can play a large role in determining which species colonize at different times.

FIGURE 4–15 Studying Succession  These Forest Service rangers are surveying some of the plants and animals that have returned to the area around Mount Saint Helens. The volcano erupted in 1980, leaving only barren land for miles.

### 4.3 Assessment

#### Review Key Concepts

1. **Review**  What effects do pioneer species have on an environment undergoing primary succession?
   **b. Explain**  Why do communities change over time?
   **c. Apply Concepts**  When a whale or other large marine mammal dies and falls to the ocean floor, different waves of decomposers and scavengers feed off the carcass until nothing remains. Do you think this is an example of succession? Explain your reasoning.

2. **a. Review**  What is a climax community?
   **b. Relate Cause and Effect**  What kinds of conditions might prevent a community from returning to its predisturbance state?

#### VISUAL THINKING

3. Look at the photo below. If you walked from this dune in a straight line away from the beach, what kinds of changes in vegetation would you expect to see? What sort of succession is this?

---

**Assessment Answers**

1a. Pioneer species fix atmospheric nitrogen into useful forms for other organisms, break down rock, and add organic material to form soil.

1b. Communities change over time because of natural or human disturbances and because organisms alter their environment and pave the way for other species. For example, when trees grow in an area, they provide shade and cooler temperatures near the ground, allowing shade-loving organisms to move in.

2a. A climax community is the community that is the end result of ecological succession.

2b. A community might not change back to its original state due to repeated disturbances, dramatic changes in the microclimate and soil that prevent regrowth of the original climax community, or chance events that determine which species colonize an area.

3. Sample answer: You would expect to see increasing numbers and greater diversity of vegetation species and the appearance of slower-growing vegetation such as trees. This is primary succession because the dune starts out without soil or plants.

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**Address Misconceptions**

The Nature of Succession  Students commonly think that succession always leads to a predetermined climax community. Address this misconception by describing how random factors can influence the outcome of succession. For example, you might discuss such factors as wind direction, rainfall, and the organisms that happen to be actively breeding immediately after a disturbance.

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**Assess and Remediate**

**EVALUATE UNDERSTANDING**

Ask students to make a series of labeled sketches to show how either primary or secondary succession occurs. Then, have students complete the 4.3 Assessment.

**REMEDATION SUGGESTION**

**Struggling Students** If students have trouble with Question 1c, have them reread Why Succession Occurs. Then, ask them whether a whale carcass changes the environment of the ocean floor and whether the types of organisms that live off of it change over time.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.
Biomes

THINK ABOUT IT: Why does the character of biological communities vary from one place to another? Why, for example, do temperate rain forests grow in the Pacific Northwest while areas to the east of the Rocky Mountains are much drier? How do similar conditions shape ecosystems elsewhere?

The Major Biomes

What abiotic and biotic factors characterize biomes?

Regional Climates

Oregon, for example, borders the Pacific Ocean. Cold ocean currents that flow from north to south have the effect of making summers in the region cooler relative to other places at the same latitude. Similarly, moist air carried by winds traveling west to east is pushed upward when it hits the Rocky Mountains. This air expands and cools, causing the moisture in the air to condense and form clouds. The clouds drop rain or snow, mainly on the upwind side of the mountains, as seen in Figure 4–16. West and east Oregon, then, have very different regional climates, and different climates mean different plant and animal communities.

Upwind Side of Mountain

Air rises and cools, releasing moisture as rain or snow.

Downwind Side of Mountain

Air descends, warms, and becomes drier, so much less rain falls.

FIGURE 4–16 The Effect of Coastal Mountains

As moist ocean air rises over the upwind side of coastal mountains, it condenses, cools, and drops precipitation. As the air sinks on the downwind side of the mountain, it expands, warms, and absorbs moisture.

Students who have lived in or visited other parts of the country to describe their climate and vegetation. Try to get descriptions of different biomes, such as southwestern deserts, prairie grasslands, and northwestern coniferous forests. Tell students they will read in this lesson why other parts of the country differ.
Biomes are described in terms of abiotic factors like climate and soil type, and biotic factors like plant and animal life. Major biomes include tropical rain forest, tropical dry forest, tropical grassland/savanna/shrubland, desert, temperate grassland, temperate woodland and shrubland, temperate forest, northwestern coniferous forest, boreal forest/taiga, and tundra. Each biome is associated with seasonal patterns of temperature and precipitation that can be summarized in a graph called a climate diagram, like the one in Figure 4–17. Organisms within each biome can be characterized by adaptations that enable them to live and reproduce successfully in the environment. The pages that follow discuss these adaptations and describe each biome’s climate.

The distribution of major biomes is shown in Figure 4–18. Note that even within a defined biome, there is often considerable variation among plant and animal communities. These variations can be caused by differences in exposure, elevation, or local soil conditions. Local conditions also can change over time because of human activity or because of the community interactions described in this chapter and the next.

**In Your Notebook** On the biome map in Figure 4–18, locate the place where you live. Which biome do you live in? Do your climate and environment match one of the descriptions better than the others. See if their climate and environment match one of the descriptions better than the others. In such cases, students should read about nearby biomes on the following pages to see if their climate and environment match one of the descriptions better than the others. If students live near the edge of a biome, they may not be able to identify their biome from the map alone. In such cases, students should read about nearby biomes on the following pages to see if their climate and environment match one of the descriptions better than the others.

**Teach**

**VISUAL SUMMARY**

Use the map in Figure 4–18 to familiarize students with the distribution of the world’s major land biomes. In addition to their own biome, ask students to identify the other biomes found in the continental United States, including Alaska.

**Ask** Which biomes are not found in the continental United States? (boreal forest/taiga, tundra, and tropical rain forest)

**Ask** Which biome is found only in the United States and Canada? (northwestern coniferous forest)

**DIFFERENTIATED INSTRUCTION**

**ELL** English Language Learners Write the term biome on the board, and tell students the word part bio- can be defined as “living things,” while the word part -me is derived from the Greek word part -oma meaning “mass or group.” Have them discuss how the meanings of these word parts make sense with the definition of biome given in the text. Point out that biomes are comprised of both living and nonliving factors.

**Address Misconceptions**

**Importance of Abiotic Factors** Students may have the misconception that biomes are distinguished on the basis of biotic factors alone, because these factors are usually the most visible. Stress that the biotic factors of biomes depend largely on abiotic factors, especially temperature and precipitation. As students learn about the major biomes in the lesson, emphasize how organisms in each biome are adapted to the climatic factors of that biome.

**Answers**

**IN YOUR NOTEBOOK** Answers will depend on where students live. If students live near the edge of a biome, they may not be able to identify their biome from the map alone. In such cases, students should read about nearby biomes on the following pages to see if their climate and environment match one of the descriptions better than the others.
**TEACH** continued

**Build Study Skills**

Divide the class into ten groups, and assign each group a different biome. Tell group members to use the information in the lesson as a starting point for becoming the “class experts” on their biome. Make sure students realize that the climate diagrams and photographs do not represent the same locations, just the same biomes. For example, there is not likely to be a tiger loose in Chennai, India and there are not herds of buffalo in Dallas, Texas. Let group members divide responsibilities among themselves. For example, different students might be responsible for researching abiotic factors, common plants, and common animals. Ask groups to give a class presentation on their biome, in which they communicate the information they have gathered and answer questions other students may have.

**DIFFERENTIATED INSTRUCTION**

**ELL** Less Proficient Readers Suggest that students create a **Compare/Contrast Table** to record important characteristics of each of the major biomes described in the lesson. They should include a row for each biome. Column headings might include: Name of Biome, Temperature, Precipitation, Soil Type, Common Plants, and Common Animals.

*Study Wkbks A/B, Appendix S20, Compare/Contrast Table. Transparencies, GO3.*

**ELL** Focus on ELL: Access Content

**ALL SPEAKERS** Pair beginning and intermediate speakers with advanced or advanced high speakers. Have pairs write the following vocabulary terms in the left column of a **T-Chart** and, below each term, a prediction of what it means: **canopy, understory, deciduous, coniferous, humus, taiga, permafrost.** Then, have pairs find the terms where they are first introduced in the lesson, read the context of the terms, and discuss whether their predictions were correct. After students have decided on the correct definitions of the terms, they should write the definitions in the right column of the chart.

*Study Wkbks A/B, Appendix S30, T-Chart. Transparencies, GO15.*

**How Science Works**

**GPS TECHNOLOGY AND WILDLIFE RESEARCH**

The development of GPS (global positioning system) technology has revolutionized how wildlife researchers gather data. The combination of GPS transmitters on collars fitted to individual animals and the network of GPS satellites in Earth’s orbit enables researchers to collect data on the precise locations of animals repeatedly throughout each day. For example, the Forest Elephant GPS Telemetry Program uses GPS collars on elephants to track their daily movements in a tropical forest biome in central Africa. GPS tracking of the animals helps scientists better understand the range and migration patterns of this little-known species in an area that is increasingly threatened by human actions, including farming, urban growth, and logging.
Biology In-Depth

CONVERGENT EVOLUTION AMONG DESERT ORGANISMS

The selective pressures of extreme abiotic factors, such as the very low precipitation in deserts, has led to convergent evolution in organisms that are only distantly related but live in the same biome type. African euphorbias and American cacti are examples. Both types of plants have evolved almost identical adaptations to the aridity of their desert biomes. Both have compact spherical shapes, spines instead of leaves, sunken stomata, and thick outer walls, all of which help reduce water loss. Both also have thick, succulent stems that store water. Another example of convergent evolution in desert animals includes North American horned lizards and Australian thorny devil lizards. Both lizards are very similar morphologically but only distantly related taxonomically.

Connect to Earth Science

Tell students that soil forms when rocks break down through weathering and humus mixes with the weathered rock particles. Explain that weathering can occur when water seeps into cracks and rock expands and contracts through repeated cycles of freezing and thawing. Particles carried by water can also weather rocks. Plant roots and burrowing animals can cause additional weathering. Humus forms when dead plant and animal materials decompose. Too much rain can cause humus to leech from soil, but too little may prevent decomposition. Have students read about temperate grasslands and temperate woodlands/shrublands. Point out that grasslands have thick, humus-rich soils, whereas woodlands/shrublands have thin, humus-poor soils.

Ask What biotic and abiotic factors in the two temperate biomes might help explain these differences in their soils?

SAMPLE ANSWER: Grasslands are likely to have more weathering and soil formation due to hot winters, moderate precipitation, and abundant plant life; they probably have more humus forming due to their dense grassy vegetation. Woodlands/shrublands are likely to have less weathering and soil formation due to cool, but not cold, winters and lower overall precipitation. They probably have less humus forming due to their scattered woody vegetation.)

DIFFERENTIATED INSTRUCTION

Special Needs

Bring in several different soil mixtures, including a mixture of loam and humus, a mixture of sand and topsoil without humus, and a compacted mixture of clay and topsoil without humus. Let students handle the soils and inspect them with a hand lens to try to identify their components. Explain why the loam-humus mixture is the most fertile and why the other soil mixtures are not as fertile. Pack an equal amount of each soil sample into a funnel, and pour water through the samples to demonstrate how the loam-humus mixture retains water (unlike the sand-soil mixture) without becoming waterlogged (like the clay-soil mixture). Guide students in identifying biomes where the three different types of soil might be found and how soil type is related to the vegetation that grows in each biome.
Use Visuals

Have students find the locations of North American temperate forests and northwestern coniferous forests on the map in Figure 4–18. Then, have them compare their climate diagrams on this page.

**Ask** How are the temperature and precipitation patterns different for the two biomes? (The summers in the temperate forest are warmer and wetter than those in the northwestern coniferous forest. The winters in the northwestern coniferous forest are warmer and wetter than those in the temperate forest.) Point out that the two forest biomes are found at some of the same latitudes but have different climates. Explain how the coastal location of northwestern coniferous forests leads to a different pattern of temperature and precipitation than that of temperate forests.

**DIFFERENTIATED INSTRUCTION**

**ELL** English Language Learners Pair English language learners with native English speakers. Have one partner read several sentences about each biome. Have the other partner try to identify which biome is being described. Then, have partners switch roles and repeat the exercise.

**LP** Less Proficient Readers Some students may be overwhelmed by the detailed descriptions of the major biomes. Suggest they choose one biotic or abiotic factor at a time and read how it varies across biomes. Once they have a sense of the overall variation in each factor, details for the individual biomes should be more meaningful.

**CHECK FOR UNDERSTANDING**

Ask students to create acrostics based on the words BIOME FACTS. Each of the ten letters in the two words should be the first letter of a sentence about a different biome so that all ten biomes are covered. The sentences should include the lesson vocabulary terms. For example, for B students might write, Biotic factors in tropical dry forests include deciduous plants that shed their leaves during the dry season. For T they might write, Temperate forests often have soils that are rich in humus from decaying leaves.

**ADJUST INSTRUCTION**

Display the acrostics in the classroom, and give students a chance to read them. Discuss as a class any statements with which they disagree.
The tundra is characterized by permafrost, a layer of permanently frozen subsoil. During the short cool summer, the ground thaws to a depth of a few centimeters and becomes soggy. In winter, the top layer of soil freezes again. This cycle of thawing and freezing, which rips and crushes plant roots, is one reason that tundra plants are small and stunted. Cold temperatures, high winds, a short growing season, and humus-poor soils also limit plant height.

- **Abiotic factors**: strong winds; low precipitation; short and soggy summers; long, cold, dark winters; poorly developed soils; permafrost
- **Biotic factors**: Plant life: By hugging the ground, mosses and other low-growing plants avoid damage from frequent strong winds. Seed dispersal by wind is common. Many plants have adapted to growth in poor soil. Legumes, for example, have nitrogen-fixing bacteria on their roots. Animal life: Many animals migrate to avoid long harsh winters. Animals that live in the tundra year-round display adaptations, among them natural antifreeze, small extremities that limit heat loss, and a varied diet.

**Which Biome?**

An ecologist collected climate data from two locations. The graph shows the monthly average temperatures in the two locations. The total yearly precipitation in Location A is 273 cm. In Location B, the total yearly precipitation is 11 cm.

1. **Interpret Graphs** What variable is plotted on the horizontal axis? On the vertical axis?
2. **Interpret Graphs** How would you describe the temperature over the course of the year in Location A? In Location B?

3. **Draw Conclusions** In which biome would you expect to find each location, given the precipitation and temperature data? Explain your answer.

4. **Analyze Data** Look up the average monthly temperature last year in the city you live in. Plot the data. Then look up the monthly rainfall for your city, and plot those data. Based on your results, which biome do you live in? Did the data predict the biome correctly?

**ANSWERS**

1. Time of year by month is plotted on the horizontal axis. Average temperature in degrees Celsius is plotted on the vertical axis.
2. In Location A, the temperature is moderate throughout the year, with little variation. In Location B, the temperature is relatively cool from November through April and hot from May through October, with a peak in July and August.
3. You would expect to find Location A in a rain forest biome, because the total precipitation is close to 3 m, and the average temperature varies little from month to month. You would expect to find Location B in a desert biome, because precipitation is very low, and the temperature varies seasonally from warm to hot.
4. Answers will vary depending on the location where students live. Advise students to format their graphs like the climate diagrams in the lesson for ease of comparison. To improve accuracy, suggest they find average monthly climate data over a several-year period. To predict the biome in which they live, they should compare their completed climate diagram to those on pages 112–115. Then, they can find their biome on the map in Figure 4–18 to see if the climate data predicted the biome correctly.
Some students may say moose and elk might prefer to graze in valleys because it would be easier to find food and water. Other students may say the animals might prefer to graze on high mountain slopes, because it would be easier to see and avoid wolves. The growth of certain plants would be curbed more in river valleys or on mountain slopes, depending on where elk prefer to graze. Students can go online to Biology.com to gather their evidence.

Assess and RemEDIATE

EVALUATE UNDERSTANDING

Make overhead transparencies of the climate diagrams for all ten major biomes. Show the transparencies, and call on students to identify each biome from the climate data. Call on other students to name plants and animals found in each biome. Then, have students complete the 4.4 Assessment.

REMEDICATION SUGGESTION

Struggling Students If students have trouble with Question 1c, suggest they choose two biomes for which they can identify a specific type of plant and animal based on their prior knowledge or the photographs in the text.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. The major biomes are tropical rain forest, tropical dry forest, tropical grassland/savanna/shrubland, desert, temperate grassland, temperate woodland and shrubland, temperate forest, northwestern coniferous forest, boreal forest, and tundra. For each biome, students can list any of the facts given for the biomes on pages 112–115.

1b. Biomes are classified in terms of abiotic factors like climate and soil type and biotic factors like typical plant and animal life.

1c. Sample answer: I chose tropical rain forests and deserts. Epiphytes grow in trees of tropical rain forests, which is an adaptation that lets them take advantage of available light. Monkeys live in the canopy of tropical rain forests, and they have adaptations for living in trees, such as hands for climbing. Cacti grow in deserts, and they have tissues that can store water, which is an adaptation to low precipitation. Some snakes that live in deserts are active only at night, which is an adaptation to high daytime temperatures.

2a. Mountain ranges and polar ice caps are not easily defined in terms of a typical community of plants and animals.

2b. Sample answer: I might begin in a grassland, pass through a pine woodland, go through a coniferous forest, and then pass through an open field of wildflowers and stunted vegetation resembling tundra. At the summit, I might find only glaciers and no plant life.

3. Students can sketch any of the biomes described in the lesson. Their sketch should include labeled drawings of typical plants and animals for that biome. It should also have a caption describing the sketch.
Getting Started

Objectives
4.5.1 Discuss the factors that affect aquatic ecosystems.
4.5.2 Identify the major categories of freshwater ecosystems.
4.5.3 Describe the importance of estuaries.
4.5.4 Describe and compare the distinct ocean zones that make up marine ecosystems.

Student Resources
Study Workbooks A/B, 4.5 Worksheets
Spanish Study Workbook, 4.5 Worksheets
BIOLOGY.com • Lesson Overview • Lesson Notes • Activity: Art Review • Assessment: Self-Test, Lesson Assessment

For corresponding lesson in the Foundation Edition, see pages 96–99.

Answers
FIGURE 4–20 Sample answer: Photic zones vary in depth depending on how clear the water is. The clearer the water, the deeper sunlight can penetrate.

Teach for Understanding

ENDURING UNDERSTANDING The existence of life on Earth depends on interactions among organisms and between organisms and their environment.
GUIDING QUESTION What are the characteristics of aquatic ecosystems?
EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand the characteristics of aquatic ecosystems. Have students work cooperatively to construct a bulletin board display of the different categories of freshwater and saltwater ecosystems discussed in the lesson. Their display should include pictures they have drawn themselves or found online, as well as labels for the names of the ecosystems, their major characteristics, and types of organisms.
Less Proficient Readers  Have students use a Main Ideas and Details Chart to organize the information about the major categories of freshwater ecosystems as they read about them on this page and the next. They should include notes on both abiotic and biotic factors for each category.

Study Wkbks A/B, Appendix S28, Main Ideas and Details Chart. Transparencies, GO13.

Focus on ELL: Access Content

ALL SPEAKERS Pair beginning and intermediate speakers with advanced or advanced high speakers. Assign each pair one of the three paragraphs with blue headings under Freshwater Ecosystems. Tell partners to read their paragraph and make drawings to illustrate it. Then, ask each pair to present a brief oral report to the class in which they identify the most important points in their paragraph and share their illustrations.

Discuss with students the interconnectedness of terrestrial and aquatic organisms along stream banks. Have them reread the paragraph with the blue heading, Rivers and Streams, to help them answer the question. Students can go online to Biology.com to gather their evidence.

Answers

FIGURE 4–21 Sample answer: Water flows in streams, but it may stay in place in bogs. Bogs have more plants growing in them than streams do.

IN YOUR NOTEBOOK Sample answer: You would expect adaptations that help anchor organisms to rocks or help them to swim against the current.

Temperature and Currents Aquatic habitats, like terrestrial habitats, are warmer near the equator and colder near the poles. Temperature in aquatic habitats also varies with depth. The deepest parts of lakes and oceans are often colder than surface waters. Currents in lakes and oceans can dramatically affect water temperature because they can carry water that is significantly warmer or cooler than would be typical for any given latitude, depth, or distance from shore.

Nutrient Availability As you learned in Chapter 3, organisms need certain substances to live. These include oxygen, nitrogen, potassium, and phosphorus. The type and availability of these dissolved substances vary within and between bodies of water, greatly affecting the types of organisms that can survive there.

Freshwater Ecosystems

What are the major categories of freshwater ecosystems?

Only 3 percent of Earth's surface water is fresh water, but that small percentage provides terrestrial organisms with drinking water, food, and transportation. Often, a chain of streams, lakes, and rivers begins in the interior of a continent and flows through several biomes to the sea. Freshwater ecosystems can be divided into three main categories: rivers and streams, lakes and ponds, and freshwater wetlands. Examples of these ecosystems are shown in Figure 4–21.

Rivers and Streams Rivers, streams, creeks, and brooks often originate from underground water sources in mountains or hills. Near a source, water has plenty of dissolved oxygen but little plant life. Downstream, sediments build up and plants establish themselves. Still farther downstream, water may meander slowly through flat areas. Animals in many rivers and streams depend on terrestrial plants and animals that live along their banks for food.

In Your Notebook What kinds of adaptations would you expect in organisms living in a fast-flowing river or stream?

SIGNIFICANCE AND LOSS OF WETLANDS

Wetlands can be invaluable ecosystems for surrounding human and natural communities. A single acre of wetland can hold up to 1.5 million gallons of floodwater. In spite of their ecological importance, wetlands were long thought to be synonymous with wastelands. They were filled in or drained for agriculture, development projects, mosquito control, and other purposes. As a result, more than half of the wetlands that once existed in the United States have been destroyed. Although destruction of wetlands has slowed since the 1970s, 60,000 acres of wetlands are still lost each year. Wetlands are almost as biologically diverse and productive as tropical rain forests. For example, as many as half of all North American bird species depend on wetlands for nesting sites or food, and almost a third of plant species live in wetlands. Loss of wetlands, therefore, is a significant cause of species extinctions.
Lakes and Ponds  The food webs in lakes and ponds often are based on a combination of plankton and attached algae and plants. Plankton is a general term that includes both phytoplankton and zooplankton. Water typically flows in and out of lakes and ponds and circulates between the surface and the benthos during at least some seasons. This circulation distributes heat, oxygen, and nutrients.

Freshwater Wetlands  A wetland is an ecosystem in which water either covers the soil or is present at or near the surface for at least part of the year. Water may flow through freshwater wetlands or stay in place. Wetlands are often nutrient-rich and highly productive, and they serve as breeding grounds for many organisms. Freshwater wetlands have important environmental functions: They purify water by filtering pollutants and help to prevent flooding by absorbing large amounts of water and slowly releasing it. Three main types of freshwater wetlands are freshwater bogs, freshwater marshes, and freshwater swamps. Saltwater wetlands are called estuaries.

Estuaries

Why are estuaries so important?

An estuary is a special kind of wetland, formed where a river meets the sea. Estuaries contain a mixture of fresh water and salt water, and are affected by the rise and fall of ocean tides. Many are shallow, which means that enough sunlight reaches the benthos to power photosynthesis. Estuaries support an astonishing amount of biomass—although they usually contain fewer species than freshwater or marine ecosystems—which makes them commercially valuable. Estuaries serve as spawning and nursery grounds for many ecologically and commercially important fish and shellfish species including bluefish, striped bass, shrimp, and crabs.

Salt marshes are temperate estuaries characterized by salt-tolerant grasses above the low-tide line and seagrasses below water. One of the largest salt marshes in America surrounds the Chesapeake Bay in Maryland (shown below). Mangrove swamps are tropical estuaries characterized by several species of salt-tolerant trees, collectively called mangroves. The largest mangrove area in America is in Florida’s Everglades National Park (shown below).

Lead a Discussion

Discuss with students how the abiotic factors of freshwater wetlands and estuaries relate to the types of organisms that live in the two categories of ecosystems.

Ask  How are the abiotic factors of freshwater wetlands and estuaries similar and different? (Both ecosystems have lots of water. Freshwater wetlands have fresh water while estuaries have a mix of fresh and salt water.)

Ask  Do the same species of aquatic organisms live in both freshwater wetlands and estuaries, and if not, why not? (No—most species are adapted to certain abiotic factors, such as salt water or fresh water but not both.)

Give examples to show why most organisms adapted to fresh water cannot tolerate salt water, and vice versa. For example, explain that saltwater fish have mechanisms for excreting excess salt from their body, whereas freshwater fish have mechanisms for concentrating salt in their body.

DIFFERENTIATED INSTRUCTION

Special Needs  Demonstrate the significance of salt tolerance in estuary plants by showing how saltwater affects a salt-intolerant plant. Place the root of a whole carrot with greens attached in a glass of fresh water. Place a second carrot in a glass of salt water. Have students compare the firmness of the leaves and stems and the flexibility of the roots over a period of a few days. Explain that carrots are not salt-tolerant plants, so salt water causes them to lose the fresh water inside their cells and become wilted. Have them infer how a salt-tolerant plant might fare under the same conditions.

Advanced Students  Ask students who have taken chemistry classes to learn about the mechanisms by which fish regulate salt balance by either pumping out sodium ions or actively taking up sodium ions, depending on whether they live in salt water or fresh water. Then, have students explain the basic chemistry underlying the mechanisms to the class.

UbD Check for Understanding

INDEX CARD SUMMARIES/QUESTIONS

Give students one index card each. On the front of their card, have them write a summary statement about factors that affect life in freshwater ecosystems. On the back of their card, ask them to write a question they still have about factors that affect life in freshwater ecosystems.

ADJUST INSTRUCTION

Collect the index cards, and share some of the more informative summary statements with the class. Then, read the questions aloud, and call on volunteers to answer them.
Lesson 4.5

Teach continued

Use Visuals

Have students do library or Internet research to identify the organisms depicted in the figure and find others not depicted. Assign each student one of the seven ocean zones, and have them photocopy, print out, or sketch images of organisms from various sources. Be sure they identify each organism, note its zone, and describe some of its salient features. Assemble the images on a bulletin board similar to Figure 4–22.

Animals in Figure 4–22: Photic Zone sea lion, herring, blue whale, great white shark, swordfish, flying fish; 200–1000 m krill-like shrimp, ocean sunfish, bigeye tuna, cod, giant squid; 1000–4000 m viperfish, dragonfish, bathypelagic anglerfish, snipe eel; 4000–10,000 m rattail, gulper eel, tripod fish

Differentiated Instruction

Special Needs Students may not be able to identify many of the organisms in Figure 4–22. Show them additional visuals of organisms found in these zones. For comparison, provide them with visuals of nocturnal organisms and animals that live in dark terrestrial environments. Have students identify some of the similar adaptive features that these organisms have evolved to survive in the dark.

Have students review the ocean zones with Art Review: Ocean Zones.

Address Misconceptions

Importance of Marine Phytoplankton A common misconception is that phytoplankton are too small to be important photosynthesizers. Tell students that oceans cover three quarters of Earth’s surface, and that each drop of ocean water down to a depth of 100 meters is home to thousands of phytoplankton. Then, tell them that phytoplankton produce 70 percent of Earth’s oxygen and are the main consumers of carbon dioxide, a greenhouse gas.

Answers

In Your Notebook Sample answer: I would expect communities in the open ocean to have lower concentrations of organisms, because there are low nutrient levels in the open ocean. Also, the organisms that live in the aphotic zone would have adaptations that help them survive in deep-water conditions.

How Science Works

Sylvia Earle: Ocean Explorer and Ground Breaker

Also called “Her Deepness” and named a “Hero for the Planet,” Dr. Sylvia Earle is a world-famous ocean explorer and marine biologist. For almost four decades, she has also been a trailblazer for women in science. For example, in 1970, when qualified women scientists often experienced difficulty obtaining positions alongside men on research teams, she led an all-female, two-week expedition to the ocean floor. In the 1990s, she was named the first female chief scientist of NOAA. During her exemplary career, Dr. Earle has led more than 60 marine expeditions and spent almost 7000 hours underwater. She has also been instrumental in developing cutting-edge technology for exploring the deep ocean—vehicles and equipment that will likely advance marine research for decades to come. A world record holder in deep sea diving, Dr. Earle is currently National Geographic Society’s Explorer-in-Residence and a vocal advocate for the oceans.
Coastal Ocean The coastal ocean extends from the low-tide mark to the outer edge of the continental shelf—the relatively shallow border that surrounds the continents. Water here is brightly lit, and is often supplied with nutrients by freshwater runoff from land. As a result, coastal oceans tend to be highly productive. Kelp forests and coral reefs are two exceptionally important coastal communities.

Open Ocean The open ocean begins at the edge of the continental shelf and extends outward. More than 90 percent of the world’s ocean area is considered open ocean. Depth ranges from about 500 meters along continental slopes to more than 10,000 meters in deep ocean trenches. The open ocean can be divided into two main zones according to light penetration: the photic zone and the aphotic zone.

The Open Ocean Photic Zone The open ocean typically has low nutrient levels and supports only the smallest species of phytoplankton. Still, because of its enormous area, most photosynthesis on Earth occurs in the sunlit top 100 meters of the open ocean.

The Open Ocean Aphotic Zone The permanently dark aphotic zone includes the deepest parts of the ocean. Food webs here are based either on organisms that fall from the photic zone above, or on chemosynthetic organisms. Deep ocean organisms, like the fish in Figure 4–23, are exposed to high pressure, frigid temperatures, and total darkness. Benthic environments in the deep sea were once thought to be nearly devoid of life but are now known to have islands of high productivity. Deep-sea vents, where superheated water boils out of cracks on the ocean floor, support chemosynthetic primary producers.

Assess and RemEDIATE

**EVALUATE UNDERSTANDING**

Play a quiz game with the class in which you name aquatic ecosystems and teams of students compete to identify their abiotic factors and the organisms that live in them. Then, have students complete the 4.5 Assessment.

**REMEDIATION SUGGESTION**

- **Struggling Students** If students have difficulty with Question 5, model an appropriate answer. For example, describe the waves and currents in the intertidal zone and explain how organisms such as barnacles and seaweed adapt to the moving water by attaching themselves to rocks.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

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**Assessment Answers**

1a. The water’s depth, temperature, flow, and amount of dissolved nutrients

1b. Sample answer: In an aphotic zone, there are no phytoplankton to produce food, because no sunlight penetrates to this depth. Organisms in the aphotic zone must obtain food in some other way than by photosynthesis or by consuming plankton.

2a. Rivers and streams, lakes and ponds, and freshwater wetlands

2b. A wetland is an ecosystem in which water either covers the soil or is present at or near the surface for at least part of the year. Wetlands are often highly productive and serve as breeding grounds for many organisms. They also purify water and help prevent flooding.

3a. Estuaries are found where rivers meet the sea. Estuaries serve as spawning and nursery grounds for many fish and shellfish.

3b. Sample answer: It might reduce the amount of freshwater entering an estuary, which would increase the salt concentration of the water.

4a. Sample answer: Intertidal zone: exposure to air and sunlight at low tides and extreme temperature changes; coastal ocean: brightly lit water and nutrients supplied by freshwater runoff; open ocean: low nutrient levels and lack of sunlight below 100 m

4b. Students’ drawings should show the intertidal zone, coastal ocean, open ocean, and an ocean trench. Photic and aphotic zones should be labeled.

5. Students can choose any three freshwater or marine ecosystems. For each, students should explain how a plant and an animal have adapted to their environment.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Abiotic Factors and Plant Selection described in Lab Manual A.

Struggling Students

A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Inform students that soil and sand sometimes contain harmful microorganisms, so they should wash their hands thoroughly after completing the lab.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 100.

NATIONAL SCIENCE EDUCATION STANDARDS

CONTENT  F.3, F.4

Pre-Lab: Abiotic Factors and Plant Selection

Problem  How can you decide which plants will thrive in a garden?

Materials  plant hardiness zone map, plant catalogs, graph paper, tape measure

Lab Manual  Chapter 4 Lab

Skills Focus  Classify, Analyze Data, Use Models

Connect to the Big idea  Why are white birch trees abundant in Minnesota, but not in the Florida Keys? Why do coconut palms grow in the Florida Keys, but not in Minnesota? Simply put, white birch trees could not tolerate the hot summers in the Keys and coconut palms could not tolerate the cold winters in Minnesota. A plant's habitat is determined by its range of tolerance for temperature and other abiotic factors. In other words, abiotic factors limit where a given plant can live.

In this lab, you will plan a garden for a specific location. You will select plants for the garden that can tolerate the abiotic factors in this location.

Background Questions

a. Review  What is an abiotic factor? List three examples other than temperature.

b. Review  What kinds of resources do plants need?

c. Relate Cause and Effect  Give an example of an adaptation that helps a plant survive in a biome with low precipitation.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. Predict  How will knowing the plant hardiness zone for your area help you plan a garden?

2. Relate Cause and Effect  What is the relationship between the last frost and the length of the growing season?

3. Form a Hypothesis  A plant species grows well in one location in a small garden but does not grow as well in another location. Suggest one possible reason for this difference.

Pre-Lab Answers

BACKGROUND QUESTIONS

a. Abiotic factors are non-living factors that influence the growth of plants. Possible abiotic factors are sunlight, precipitation, wind, humidity, and soil type.

b. Sample answer: Plants need water, light, nutrients, and space to grow.

c. Possible answers include leaves with limited surface area or leaf pores that open only at night.

PRE-LAB QUESTIONS

1. Sample answer: Knowing the plant hardiness zone will provide information about some abiotic factors. (Some students may know that suppliers of seeds and plants usually provide a range of hardiness zones for each species.)

2. Sample answer: The earlier the last frost occurs, the longer the growing season.

3. Sample answer: One location may have direct sunlight all day and the other may be in the shade for most of the day.
**4 Study Guide**

**Interdependence in Nature**

An organism’s tolerance range for temperature, precipitation, and other abiotic factors helps determine where it lives. Biotic factors, such as competition, predation, and herbivory also help to determine an organism’s potential habitat and niche.

**4.1 Climate**

A region’s climate is defined by year-after-year patterns of temperature and precipitation.

Global climate is shaped by many factors, including solar energy trapped in the biosphere, latitude, and the transport of heat by winds and ocean currents.

**4.2 Niches and Community Interactions**

A niche is the range of physical and biological conditions in which a species lives and the way the species obtains what it needs to survive and reproduce.

By causing species to divide resources, competition helps determine the number and kinds of species in a community and the niche each species occupies.

Predators can affect the size of prey populations in a community and determine the places prey can live and feed.

Herbivores can affect both the size and distribution of plant populations in a community and can determine the places that certain plants can survive and grow.

Biologists recognize three main classes of symbiotic relationships in nature: mutualism, parasitism, and commensalism.

**4.3 Succession**

Ecosystems change over time, especially after disturbances, as some species die out and new species move in.

Secondary succession in healthy ecosystems following natural disturbances often reproduces the original climax community. Ecosystems may or may not recover from human-caused disturbances.

Ecological succession primary succession secondary succession

**4.4 Biomes**

Biomes are described in terms of abiotic factors like climate and soil type, and biotic factors like plant and animal life.

Mountain ranges and polar ice caps are not usually classified into biomes because they are not easily defined in terms of a typical community of plants and animals.

Canopy coniferous permafrost
Understory humus deciduous taiga

**4.5 Aquatic Ecosystems**

Aquatic organisms are affected primarily by the water’s depth, temperature, flow, and amount of dissolved nutrients.

Freshwater ecosystems can be divided into three main categories: rivers and streams, lakes and ponds, and freshwater wetlands.

Estuaries serve as spawning and nursery grounds for many ecologically and commercially important fish and shellfish species.

Ecologists typically divide the ocean into zones based on depth and distance from shore.

Photic zone benthos wetland
Aphotic zone plankton estuary

**Performance Tasks**

**SUMMATIVE TASK** Have pairs of students select one of the land biomes or aquatic ecosystems described in the chapter and create a scrapbook highlighting its abiotic and biotic factors. Tell students to convey the information about their biome with photographs, maps, graphs, and short passages of text.

**TRANSFER TASK** Ask groups of students to choose a specific region of a land biome or aquatic ecosystem that is threatened by human actions and create a Web site about the problem and potential solutions. The Web site should include information on why the ecosystem is threatened, why it is important, what is being done to protect it, and what individuals can do to help.

**Answers**

**THINK VISUALLY**

Students’ concept maps should show that ecosystems are determined by abiotic factors, including nutrients, light, and oxygen; and by biotic factors, including the community interactions of predation, competition, and symbiosis.

Ecosystems and Communities 123
Lesson 4.1

UNDERSTAND KEY CONCEPTS
1. b 2. d
3. Weather is the day-to-day condition of Earth’s atmosphere. Climate refers to average conditions over long periods.
4. Solar energy trapped in the biosphere, latitude, and the transport of heat by winds and ocean currents

THINK CRITICALLY
5. The curvature of Earth’s surface causes sunlight to strike the surface near the poles at an angle, so solar energy is spread out over a larger area at the poles than at the equator. This difference in the distribution of solar energy at different latitudes explains climate zones. As Earth revolves around the sun, sunlight strikes different regions at angles that vary from summer to winter. This difference in the distribution of solar energy at different times of the year explains seasons.
6. The white paint reflects much of the sunlight so that it does not pass into the greenhouse where it would be trapped as heat.

Lesson 4.2

UNDERSTAND KEY CONCEPTS
7. d 8. b
9. An organism’s habitat is the general location where it lives. Its niche includes not only where it lives but also how it lives, including which abiotic factors it needs, how it reproduces, what it eats, and how it obtains its food.
10. No two species can occupy exactly the same niche at exactly the same time.

THINK CRITICALLY
11. In predation, one organism captures, kills, and eats another organism. In parasitism, one organism lives in or on another organism and uses it for food or other purposes without killing it.
12. Members of the same species have exactly the same niche. Therefore, they are in direct competition for the same resources in their area. Members of two different species are likely to have somewhat different niches, so while they may need some of the same resources, they are likely to use them at different times or in different ways, which means that they do not compete so intensely for them.
13. Sample answer: I reside in a city with a temperate climate. I live in a house with other members of my family and a dog. I interact with many humans, and I take my dog for walks. I eat a variety of plant and animal foods that come from all over the world, and I buy them at local supermarkets and restaurants.

Lesson 4.3

UNDERSTAND KEY CONCEPTS
14. d 15. d
16. Primary succession
17. Natural disturbances and human-caused disturbances

THINK CRITICALLY
18. Secondary succession; in 5 years, small trees will probably have started to grow.
**Lesson 4.4**

**UNDERSTAND KEY CONCEPTS**

20. a. canopy. b. taiga. c. savanna. d. understory.

21. Permafrost characterizes the biome called a. taiga. b. savanna. c. taiga. d. boreal forest.

22. What is a biome?

23. Why are plants generally few and far between in a desert?

**THINK CRITICALLY**

24. Apply Concepts Although the amount of precipitation is low, most parts of the tundra are very wet during the summer. How would you explain this apparent contradiction?

25. Infer Deciduous trees in tropical dry forests lose water through their leaves every day. During summers with adequate rain, the leaves remain on the trees. During the cold dry season, the trees drop their leaves. In an especially dry summer, how might the adaptation of dropping leaves enable a tree to tolerate the drought?

26. Infer Consider these two biomes: (1) the temperate grassland and (2) the temperate woodland and shrubland. Coyotes live in both biomes. Describe two adaptations that might enable coyotes to tolerate conditions in both biomes.

**4.5 Aquatic Ecosystems**

**Understand Key Concepts**

27. Organisms that live near or on the ocean floor are called a. parasites. b. benthos. c. plankton. d. mangroves.

28. What is the meaning of the term plankton? Name the two types of plankton.

29. What are three types of freshwater wetlands?

30. How are salt marshes and mangrove swamps alike? How are they different?
Lesson 4.5

UNDERSTAND KEY CONCEPTS
27. b
28. Plankton is a combination of phytoplankton (photosynthetic algae) and zooplankton (tiny free-floating animals that eat phytoplankton).
29. rivers and streams, lakes and ponds, and freshwater wetlands
30. Both are estuaries formed where a river meets the sea. Salt marshes are temperate zone estuaries where salt-tolerant grasses and seagrasses grow. Mangrove swamps are tropical zone estuaries where salt-tolerant trees, called mangroves, grow.

THINK CRITICALLY
31. Sample answer: Some animals are able to produce light chemically in order to lure prey. Other animals have very sensitive feelers for detection in the dark. Still others have robust vascular systems that allow them to withstand great pressures and cold temperatures.
32. Sample answer: Filling in a salt marsh to create a coastal resort might bring money into the local economy. However, it would destroy the spawning and nursery grounds for fish and shellfish species, which could harm the local economy. Therefore, I would not support the proposal.

Connecting Concepts

USE SCIENCE GRAPHICS
33. A coral reef is most productive, probably because they are found in coastal ocean zones where the shallow water is brightly lit and often supplied with nutrients from freshwater runoff.
34. because it covers such a huge portion of Earth’s surface
35. Answers will vary. Check that students have correctly identified two abiotic factors that affect the productivity of each ecosystem.
36. Sample answer: I think its primary productivity is likely greater, because it gets abundant precipitation for three seasons of the year and is less susceptible to the frequent forest fires that decrease productivity in the savanna.

WRITE ABOUT SCIENCE
37. Answers will vary depending on which biomes students choose. They should identify the biome’s abiotic and biotic factors and explain how they are interrelated, using examples.
38. Abiotic factors determine the types of pioneer species that can live in an area and that are likely to be involved in primary succession following a volcanic eruption.

Think Critically
31. Form a Hypothesis The deep ocean lies within the aphotic zone and is very cold. Suggest some of the unique characteristics that enable animals to live in the deep ocean.
32. Form an Opinion A developer has proposed filling in a salt marsh to create a coastal resort. What positive and negative effects do you think this proposal would have on wildlife and local residents? Would you support the proposal?

Use Science Graphics
The following table presents primary productivity (measured in grams of organic matter produced per year per square meter) for several ecosystems. Use the table below to answer questions 33 and 34.

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Aquatic Ecosystems</th>
<th>Average Primary Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coral reef</td>
<td>2500</td>
<td></td>
</tr>
<tr>
<td>Estuary</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td>Open ocean</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>Land Ecosystems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropical rain forest</td>
<td>2200</td>
<td></td>
</tr>
<tr>
<td>Tropical savanna</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>Tundra</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>

39. Interpret Graphs The greatest volume of glacial ice was lost
   b. between 1980 and 1990.
   d. before 1960.

40. Relate Cause and Effect The most reasonable explanation for the loss of glacier mass since 1960 is
   a. an increase in the total productivity of the world’s oceans.
   b. a gradual rise in Earth’s average temperature.
   c. an increase in the total amount of ice at Earth’s poles.
   d. an increase in the sun’s output of radiant energy.
Answers

1. C
2. B
3. B
4. A
5. C
6. D
7. B
8. A
9. D
10. Lichens are especially well adapted to play the role of pioneer organisms because they can grow on bare rock, fix atmospheric nitrogen into useful forms for other organisms, break down rock, and add organic material to form soil.

Questions 8–9

Month-by-month climate data for the city of Lillehammer, Norway, is shown in the table below.

<table>
<thead>
<tr>
<th>Climate Data for Lillehammer, Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
</tr>
<tr>
<td>Jan.</td>
</tr>
<tr>
<td>Feb.</td>
</tr>
<tr>
<td>Mar.</td>
</tr>
<tr>
<td>Apr.</td>
</tr>
<tr>
<td>May</td>
</tr>
<tr>
<td>June</td>
</tr>
<tr>
<td>July</td>
</tr>
<tr>
<td>Aug.</td>
</tr>
<tr>
<td>Sept.</td>
</tr>
<tr>
<td>Oct.</td>
</tr>
<tr>
<td>Nov.</td>
</tr>
<tr>
<td>Dec.</td>
</tr>
</tbody>
</table>

8. Which type of graph would be BEST suited to showing the precipitation data from the table?
   A bar graph  
   C pie chart  
   B pictograph  
   D scatter plot

9. For a given set of data, the range is the difference between highest and lowest points. The average annual temperature range, in °C, for Lillehammer is approximately
   A −8.  
   B 8.5.  
   C 16.5.  
   D 24.5.

Open-Ended Response

10. Why are lichens especially well adapted to play the role of pioneer organisms in an ecological succession?

Test-Taking Tip

REPHRASE THE QUESTION

Advise students to rewrite difficult test questions in their own words. This will help them better understand what the questions are asking so they can write more appropriate answers. However, caution them to avoid changing the meaning of questions when they rephrase them. Suggest they ask for clarification, if possible, of any questions they still do not understand after rephrasing them.
Connect to the Big Idea

Use the photograph of red crabs on Christmas Island to introduce ideas about population size and factors affecting population size. Ask students to identify some of the factors that could cause a change in the number of red crabs on Christmas Island. (Sample answers: amount of food available, weather, human actions) Have students predict what would happen to the red crab population as the result of a drought, a hurricane, or the introduction of a predator to the ecosystem. (Answers will vary, but all responses should be well reasoned.) Ask them to anticipate the answer to the question, What factors contribute to changes in populations?

Have students read over the Chapter Mystery. Ask them to brainstorm a list of reasons why the rabbit population in Australia grew so rapidly. After they have completed Chapter 5, have them explain how the solution to the Chapter Mystery is related to the Chapter 5 Essential Question: What factors contribute to changes in populations?

Have students preview the chapter vocabulary terms using the Flash Cards.

Understanding by Design

Chapter 5 explores ideas about populations and factors affecting population growth, in relation to the Big Idea, Interdependence in Nature. The graphic organizer at the right shows how chapter concepts help students build toward this Big Idea and the Unit 2 Enduring Understanding of how the existence of life on Earth depends on interactions among organisms and between organisms and their environment.

PERFORMANCE GOALS

Throughout Chapter 5, students are challenged to answer caption questions and complete In Your Notebook activities to show understanding of populations and the factors that affect them. At the end of the chapter, students must synthesize chapter concepts to help them predict the impact of a change in medical technology on the U.S. population and to help them write a science-fiction story relating the concepts of carrying capacity, limiting factors, and human population growth.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

I, II, III, IV

CONTENT

C.4.d, C.4.e, F.2, F.3, F.4, F.6, G.1, G.2

INQUIRY

A.1.b, A.1.c, A.1.d, A.2.a, A.2.b, A.2.d
INSIDE:
• 5.1 How Populations Grow
• 5.2 Limits to Growth
• 5.3 Human Population Growth

Chapter 5
Big Idea:
Interdependence in Nature

Chapter 5 EQ:
What factors contribute to changes in populations?

What’s Online

CHAPTER MYSTERY
A PLAGUE OF RABBITS
In 1859, an Australian farmer released 24 wild European rabbits from England on his ranch. “A few rabbits” he said, “could do little harm and might provide a touch of home, in addition to a spot of hunting.”

Seven years later, he and his friends shot 14,253 rabbits. In ten years, more than 2 million rabbits were hunted on that farm alone! But hunters’ glee turned into nationwide despair. That “touch of home” was soon covering the countryside like a great gray blanket. The millions of rabbits devoured native plants and pushed native animals to near extinction. They made life miserable for sheep and cattle ranchers.

These cute, fuzzy creatures weren’t a problem in England. Why did they turn into a plague in Australia? Could they be stopped? How? As you read this chapter, look for clues on factors that affect population growth. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the rabbit population mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

DATA ANALYSIS
Students analyze data to make predictions about zebra mussel population growth.

ART REVIEW
Reinforce limiting factors using this drag-and-drop activity.

INTERACTIVE ART
Students manipulate factors to see how predator and prey populations would change over several generations.

ART IN MOTION
This animated time series shows change in the world population age structure.
How Populations Grow

Key Questions
- How do ecologists study populations?
- What factors affect population growth?
- What happens during exponential growth?
- What is logistic growth?

Vocabulary
- population density • age structure • immigration • emigration • exponential growth • logistic growth • carrying capacity

THINK ABOUT IT
In the 1950s, a fish farmer in Florida tossed a few plants called hydrilla into a canal. Hydrilla was imported from Asia for use in home aquariums because it is hardy and adaptable. The fish farmer assumed that hydrilla was harmless. But the few plants he tossed away reproduced quickly... and kept on reproducing. Today, their offspring strangle waterways across Florida and many other states. Tangled stems snag boats in rivers and overtake habitats; native water plants and animals are disappearing. Why did these plants get so out of control? Is there any way to get rid of them?

Meanwhile, people in New England who fish for a living face a different problem. Despite hard work and new equipment, their catch has dropped dramatically. The cod catch in one recent year was 3048 metric tons. Back in 1982, it was 57,200 metric tons—almost 19 times higher! Where did all the fish go? Can anything be done to increase their numbers?

Describing Populations

At first glance, the stories of hydrilla and cod may seem unrelated. One is about plants growing out of control, and the other is about fish disappearing. Yet both involve dramatic changes in the size of a population. Recall that a population is a group of organisms of a single species that lives in a given area.

Researchers study populations’ geographic range, density and distribution, growth rate, and age structure.

FIGURE 5–1 Invasive Hydrilla
Hydrilla has spread through most of Florida in just a few decades. Efforts to control the waterweed cost millions of dollars a year.

ACTIVATE PRIOR KNOWLEDGE
Have students identify populations of living things found in the area where they live. Then, ask them to identify factors that might affect the size of these populations. Write their responses on the board. As students read the lesson, have them revise and add to the lists.

TEACH FOR UNDERSTANDING

ENDURING UNDERSTANDING
The existence of life on Earth depends on interactions among organisms and between organisms and their environment.

GUIDING QUESTION
How do populations grow?

EVIDENCE OF UNDERSTANDING
After completing the lesson, give students the following assessment to show their understanding of exponential growth in populations. Have students work in pairs to model exponential growth in a population of bacteria. First, tell students to draw a single small circle, representing a single bacterium, on a piece of paper. Under the single circle, have them draw two circles, representing the second generation of the population (after the original bacterium divides). Then, have them draw circles to represent the next four generations of bacteria. Finally, have them write a paragraph that explains how this model shows exponential population growth.
**Geographic Range** The area inhabited by a population is called its geographic range. A population’s range can vary enormously in size, depending on the species. A bacterial population in a rotting pumpkin, for example, may have a range smaller than a cubic meter. The population of cod in the western Atlantic, on the other hand, covers a range that stretches from Greenland down to North Carolina. The natural range of one hydrilla population includes parts of southern India and Sri Lanka. The native range of another hydrilla population was in Korea. But humans have carried hydrilla to so many places that its range now includes every continent except Antarctica, and it is found in many places in the United States.

**Density and Distribution** Population density refers to the number of individuals per unit area. Populations of different species often have very different densities, even in the same environment. For example, a population of ducks in a pond may have a low density, while fish in the same pond community may have a higher density. Distribution refers to how individuals in a population are spaced out across the range of the population—randomly, uniformly, or mostly concentrated in clumps, as shown in Figure 5–2.

**Growth Rate** A population’s growth rate determines whether the size of the population increases, decreases, or stays the same. Hydrilla populations in their native habitats tend to stay more or less the same size over time. These populations have a growth rate of around zero. In other words, they neither increase nor decrease in size. The hydrilla population in Florida, by contrast, has a high growth rate—which means that it increases in size. Populations can also decrease in size, as cod populations have been doing. The cod population has a negative growth rate.

**Age Structure** To fully understand a plant or animal population, researchers need to know more than just the number of individuals it contains. They also need to know the population’s age structure—the number of males and females of each age a population contains. Why? Because most plants and animals cannot reproduce until they reach a certain age. Also, among animals, only females can produce offspring.

**How Science Works**

**GEOGRAPHIC RANGE AND CLIMATE CHANGE**

Climate is one of the factors that determine the range of a species. A species’ range can change, therefore, as a result of climate change. Predicting the effects of climate change on species’ ranges is an active area of ecological research. Some ecologists use computer modeling as a tool for this research; a variety of computer modeling systems have been developed for this use. Although current modeling systems have some limitations, scientists can still use these results to assess the vulnerability of species to extinction due to climate change.

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**Teach**

**Lead a Discussion**

Have students read the descriptions of the four characteristics of populations on this page.

**Ask** What would happen to a population’s density if the population size stayed the same while its geographic range decreased? (Its density would increase.)

**Ask** Which characteristic most directly determines if a population increases or decreases in size over time? (growth rate)

---

**DIFFERENTIATED INSTRUCTION**

**ELL** Focus on ELL: Extend Language

**BEGINNING AND INTERMEDIATE SPEAKERS** Use a Vocabulary Word Map to help students organize information about populations. Provide each student with a blank Vocabulary Word Map, and draw a large one on the board. Write the word populations in the top box. Have students copy the word into their own map and practice pronouncing it aloud. Then, have them use the information on this page to fill in the four attribute boxes. Beginning speakers can use single words or short phrases to fill in the attribute boxes. Encourage intermediate speakers to use longer phrases or sentences. Have students share their responses orally, and use their responses to fill in the map on the board.

**Study Wkbks A/B, Appendix S32, Vocabulary Word Map. Transparencies, G017.**
LESSON 5.1

Use Visuals

Use Figure 5–3 to help students visualize the factors that affect population growth.

Ask What two factors add individuals to the fish population? (births and immigration)

Ask What two factors remove individuals from the fish population? (deaths and emigration)

Ask If the fish population stays the same size for a one-year period, what can you assume about the number of individuals removed from the population due to death and emigration during that time? (That number is equal to the number of individuals added to the population by birth or immigration.)

DIFFERENTIATED INSTRUCTION

ELL English Language Learners Write the term immigration on the board. Explain that the word immigration is formed using the prefix im- meaning “in.” The root word migrare is based on the Latin word migrare, meaning “to move from one location to another.” Then, write the word emigration on the board. Tell students the word part e- means “out.” Ask them to relate this to the meaning of the term emigration.

Students should recognize that the rabbit population in Australia exhibited exponential growth. Have pairs of students discuss why the exponential growth of the rabbit population was problematic. Students can go online to Biology.com to gather their evidence.

Population Growth

What factors affect population growth?

What determines whether a population grows, shrinks, or stays the same size? A population will increase or decrease in size depending on how many individuals are added to it or removed from it, as shown in Figure 5–3. The factors that can affect population size are the birthrate, death rate, and the rate at which individuals enter or leave the population.

Birthrate and Death Rate Populations can grow if more individuals are born than die in any period of time. In other words, a population can grow when its birthrate is higher than its death rate. If the birthrate equals the death rate, the population may stay the same size. If the death rate is greater than the birthrate, the population is likely to shrink. Note that birth means different things in different species. Lions are born much like humans are born. Codfish, however, release eggs that hatch into new individuals.

Immigration and Emigration A population may grow if individuals move into its range from elsewhere, a process called immigration (im uh gray shun). Suppose, for example, that an oak grove in a forest produces a bumper crop of acorns one year. The squirrel population in that grove may increase as squirrels immigrate in search of food. On the other hand, a population may decrease in size if individuals move out of the population’s range, a process called emigration (em uh gray shun). For example, a local food shortage or overcrowding can cause emigration. Young animals approaching maturity may emigrate from the area where they were born to find mates or establish new territories.

Exponential Growth

What happens during exponential growth?

If you provide a population with all the food and space it needs, protect it from predators and disease, and remove its waste products, the population will grow. Why? The population will increase because members of the population will be able to produce offspring. After a time, those offspring will produce their own offspring. Then, the offspring of those offspring will produce offspring. So, over time, the population will grow.

But notice that something interesting will happen: The size of each generation of offspring will be larger than the generation before it. This situation is called exponential (eks poh sex shul) growth. In exponential growth, the larger a population gets, the faster it grows. Under ideal conditions with unlimited resources, a population will grow exponentially. Let’s examine why this happens under different situations.

Check for Understanding

DEPTH OF UNDERSTANDING

Ask If a population’s birthrate is greater than the death rate, what can be determined about the overall change in population size? (A student with a superficial understanding of the factors that affect population size will automatically assume that the population is growing without taking into consideration the impact of immigration and emigration on population size. A student with a sophisticated understanding would suggest that the overall change in population size cannot be determined without information about immigration and emigration rates.)

ADJUST INSTRUCTION

If students demonstrate a superficial understanding of the question, use a jar of marbles as a model of a population. Model births and immigration by adding marbles; model deaths and emigration by removing marbles.
**Organisms That Reproduce Rapidly** We begin a hypothetical experiment with a single bacterium that divides to produce two cells every 20 minutes. We supply it with ideal conditions—and watch. After 20 minutes, the bacterium divides to produce two bacteria. After another 20 minutes, those two bacteria divide to produce four cells. At the end of the first hour, those four bacteria divide to produce eight cells.

Do you see what is happening here? After three 20-minute periods, we have $2 \times 2 \times 2$, or 8 cells. Another way to say this is to use an exponent: $2^3$ cells. In another hour (six 20-minute periods), there will be $2^6$, or 64 bacteria. In just one more hour, there will be $2^9$, or 512. In one day, this bacterial population will grow to an astounding 4,720,000,000,000,000,000,000,000,000,000,000 individuals. What would happen if this growth continued without slowing down? In a few days, this bacterial population would cover the planet!

If you plot the size of this population on a graph over time, you get a J-shaped curve that rises slowly at first, and then rises faster and faster, as shown in Figure 5–4. If nothing interfered with this kind of growth, the population would become larger and larger, faster and faster, until it approached an infinitely large size.

**Organisms That Reproduce Slowly** Of course, many organisms grow and reproduce much more slowly than bacteria. For example, a female elephant can produce a single offspring only every 2 to 4 years. Newborn elephants take about 10 years to mature. But as you can see in Figure 5–4, if exponential growth continued, the result would be impossible. In the unlikely event that all descendants of a single elephant pair survived and reproduced, after 750 years there would be nearly 20 million elephants!

**Organisms in New Environments** Sometimes, when an organism is moved to a new environment, its population grows exponentially for a time. That’s happening with hydrilla in the United States. It also happened when a few European gypsy moths were accidentally released from a laboratory near Boston. Within a few years, these plant-eating pests had spread across the northeastern United States. In peak years, they devoured the leaves of thousands of acres of forest. In some places, they formed a living blanket that covered the ground, sidewalks, and cars.

**In Your Notebook** Draw a growth curve for a population of waterweed growing exponentially.

---

**Quick Facts**

**BIOTIC POTENTIAL**

The graphs on this page represent how a population would grow in the presence of unlimited resources and the absence of predation and disease. The size a population would reach in these conditions, when all offspring survive and produce young, is called the biotic potential of a species. In order for this to happen, there must not be any factors present that limit population growth. In nature, no population ever reaches its biotic potential. The factors that prevent this unlimited growth, called limiting factors, are the focus of Lesson 5.2.

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**Connect to Math**

Have students examine the graphs in Figure 5–4.

**Ask** How does the shape of the line representing the growth of the bacterial population compare to the shape of the line representing the growth of the elephant population? (They are very similar.)

**Ask** How do the graphs differ? (Sample answers: The x-axis of the bacteria graph is marked in 2-hour increments; the x-axis of the elephant graph is marked in 250-year increments. The y-axis of the graph representing the bacterial population is marked in increments of 100,000; the y-axis of the graph representing the elephant population is marked in increments of 5 million.)

**Ask** Why are different time increments used in the two graphs? (Elephants reproduce at a much slower rate than bacteria.)

**DIFFERENTIATED INSTRUCTION**

**Advanced Students** Have students write a paragraph explaining why, in natural settings, exponential growth does not continue indefinitely for any species. Have students share their paragraphs with the class.

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**Answers**

**IN YOUR NOTEBOOK** Students should use a J-shaped curve to show the exponential growth of the waterweed population.
Have students examine the graph in Figure 5–5. Explain that the shape of the line represents the rate at which the population grows. Tell students a line with a steep, positive slope represents a population growing rapidly. A flat line represents a population that stays a steady size. Have students point to the part of the graph that shows a rapidly growing population. Then, ask them to point to a part of the graph representing a population that stays a steady size.

Address Misconceptions

Population Growth Models Several common misconceptions about population growth are revealed when students are asked to graph population growth. Two common errors in students’ graphs are: (1) the omission of Phase II, in which growth slows—students show rapid growth followed by abrupt change to no growth; and (2) the placement of the initial point representing the starting population at the origin, or (0, 0), thus implying the impossible—a population growing from zero. Use the graph in Figure 5–5 to help address these common misconceptions. Point out Phase II in the graph, and explain that this phase represents a population that is still growing, but more slowly than during Phase I. Also point out the initial point on the graph, and have students note that it is not at the origin. Remind them that all populations must start with at least one individual (in the case of asexually reproducing organisms) or one pair of organisms.

Help students understand exponential growth and logistic growth with Data Analysis: Invasion of Zebra Mussels.

Logistic Growth

What is logistic growth?

This ability of populations to grow exponentially presents a puzzle. Obviously, bacteria, elephants, hydrilla, and gypsy moths don’t cover the Earth. This means that natural populations don’t grow exponentially for long. Sooner or later, something—or several “somethings”—stops exponential growth. What happens?

Phases of Growth One way to begin answering this question is to watch how populations behave in nature. Suppose that a few individuals are introduced into a real-world environment. Figure 5–5 traces the phases of growth that the population goes through.

Phase 1: Exponential Growth After a short time, the population begins to grow exponentially. During this phase, resources are unlimited, so individuals grow and reproduce rapidly. Few individuals die, and many offspring are produced, so both the population size and the rate of growth increase more and more rapidly.

Phase 2: Growth Slows Down In real-world populations, exponential growth does not continue for long. At some point, the rate of population growth begins to slow down. This does not mean that the population size decreases. The population still grows, but the rate of growth slows down, so the population size increases more slowly.

Phase 3: Growth Stops At some point, the rate of population growth drops to zero. This means that the size of the population levels off. Under some conditions, the population will remain at or near this size indefinitely.
The Logistic Growth Curve  The curve in Figure 5–5 has an S-shape that represents what is called logistic growth. Logistic growth occurs when a population’s growth slows and then stops, following a period of exponential growth. Many familiar plant and animal populations follow a logistic growth curve.

What kinds of changes in a population’s characteristics can produce logistic growth? Remember that a population grows when more organisms are born (or added to it) than die (or leave it). Thus, population growth may slow for several reasons. Growth may slow because the population’s birthrate decreases. Growth may also slow if the death rate increases—or if births fall and deaths rise together. Similarly, population growth may slow if the rate of immigration decreases, the rate of emigration increases, or both. There are several reasons why these rates might change in a population, as you will see in the next lesson.

Carrying Capacity  When the birthrate and the death rate are the same, and when immigration equals emigration, population growth stops. The population may still rise and fall somewhat, but the ups and downs average out around a certain population size. If you look again at Figure 5–5, you will see a broken, horizontal line through the region of the graph where population growth levels off. The point at which that line intersects the y-axis represents what ecologists call the carrying capacity. Carrying capacity is the maximum number of individuals of a particular species that a particular environment can support. Once a population reaches the carrying capacity of its environment, a variety of factors act to stabilize it at that size.

Assessment Answers

1a. geographic range, density and distribution, growth rate, age structure

1b. Sample answer: Gray squirrels have a very large geographic range.

2a. births, immigration, deaths, emigration

2b. The dandelion population will probably grow. Eventually, dandelions might take over the lawn.

3a. A population grows exponentially when it has all of the resources it needs and disease and predation do not occur.

3b. because with each generation, the number of organisms producing offspring increases, resulting in a rapid increase in population size

4a. A logistic growth curve has an S-shape.

4b. when a population’s growth slows following a period of exponential growth and then stops at or near the carrying capacity

4c. Sample answer: Events that destroy a part of an environment, such as a forest fire, would change the carrying capacity of the environment.

Multiplying Rabbits

Suppose that a pair of rabbits produces six offspring: three males and three females. Assume that no offspring die.

1. Calculate If each pair of rabbits breeds only once, how many offspring would be produced each year for five generations?

2. Interpret Graphs

Construct a graph of your data. Plot time on the x-axis and population on the y-axis. What type of growth is the rabbit population going through after 5 years?

3. What kinds of changes in a population’s characteristics can produce logistic growth? Remember that a population grows when more organisms are born (or added to it) than die (or leave it). Thus, population growth may slow for several reasons. Growth may slow because the population’s birthrate decreases. Growth may also slow if the death rate increases—or if births fall and deaths rise together. Similarly, population growth may slow if the rate of immigration decreases, the rate of emigration increases, or both. There are several reasons why these rates might change in a population, as you will see in the next lesson.

Carrying Capacity  When the birthrate and the death rate are the same, and when immigration equals emigration, population growth stops. The population may still rise and fall somewhat, but the ups and downs average out around a certain population size. If you look again at Figure 5–5, you will see a broken, horizontal line through the region of the graph where population growth levels off. The point at which that line intersects the y-axis represents what ecologists call the carrying capacity. Carrying capacity is the maximum number of individuals of a particular species that a particular environment can support. Once a population reaches the carrying capacity of its environment, a variety of factors act to stabilize it at that size.
**Teach**

**Lead a Discussion**

Have students read the information about zebra and quagga mussels, then apply what they have learned about populations to this issue. Explain that ships carry water in ballast tanks to maintain buoyancy and stability. The waters are loaded and discharged as the ships travel from port to port. Help students understand how zebra and quagga mussels can be picked up in ballast water by explaining that mussel larvae are tiny and free-swimming. Distinguish this from the adult stage of the mussels’ life cycle, in which the mussel typically remains affixed to a hard surface.

**Ask** Why does the population growth of zebra and quagga mussels in Great Lakes ecosystems differ from the population growth of these mussels in their native habitats? *(Sample answer: Factors that limited their growth in their native habitat do not exist in their new habitat.)*

**Ask** How has the geographic range of zebra mussels changed between the mid-1980s and now? *(It has increased greatly.)*

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**Answers**

**RESEARCH AND DECIDE**

1. **Answers may vary.** Students should conclude that the zebra mussel populations are showing exponential growth, and should back up their conclusions with relevant facts from their research.

2. **Answers may vary.** Students should conclude that the best control is the prevention of further proliferation. According to the USGS, no biological control methods to date have worked, and the release of predators to eat the mussels would be ineffective. To prevent further proliferation of the mussels, people should clean off boats and boat trailers, avoid dumping bait into rivers and lakes (there could be mussel larvae in bait buckets), and decontaminate SCUBA diving gear.

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**Invasive Species Management Should Focus on Control and Prevention**

Others argue that efforts to physically remove or chemically poison invasive mussels offer only temporary control. The population bounces right back. These removal efforts are also incredibly expensive. In the Great Lakes alone, more than $200 million is spent each year in efforts to get rid of zebra and quagga mussels.

Therefore, many scientists believe that there is no way to remove these mussels and other established invasive species. Instead, these scientists attempt to control the growth of populations and prevent transfer of invasive species to new areas. One regulation, for example, could require boaters to filter and chemically clean all ballast water. Meanwhile, the search continues for some kind of control that naturally limits mussel numbers when they rise.

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**Research and Decide**

1. **Analyze the Viewpoints** Research the current status of invasive mussel populations and the approaches being used to prevent the spread of these and other invasive aquatic species. What trends are zebra mussel populations showing?

2. **Form an Opinion** What kinds of natural population controls do you think would manage these invasive mussels most effectively? Why?

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**Biology In-Depth**

**HUMAN IMPACT ON GEOGRAPHIC RANGE OF SPECIES**

The explosive population growth of invasive species, such as zebra mussels, is an illustration of the impact of humans on the population growth of other species. In the case of invasive species, human action increases the geographic range of a species, sometimes resulting in a huge increase in population size. Other human actions, such as habitat destruction due to development, can have the opposite effect. By decreasing the geographic range of a species, humans can cause the population size of the species to decrease, reflecting a decrease in carrying capacity.
Limits to Growth

THINK ABOUT IT Now that you’ve seen how populations typically grow in nature, we can explore why they grow as they do. If populations tend to grow exponentially, why do they often follow logistic growth? In other words, what determines the carrying capacity of an environment for a particular species? Think again about hydrilla. In its native Asia, populations of hydrilla increase in size until they reach carrying capacity, and then population growth stops. But here in the United States, hydrilla grows out of control. The same is true of gypsy moths and many other introduced plant and animal species. Why does a species that is “well-behaved” in one environment grow out of control in another?

Limiting Factors
What factors determine carrying capacity?
Recall that the productivity of an ecosystem can be controlled by a limiting nutrient. A limiting nutrient is an example of a general ecological concept: a limiting factor. In the context of populations, a limiting factor is a factor that controls the growth of a population.

As shown in Figure 5–6, there are several kinds of limiting factors. Some—such as competition, predation, parasitism, and disease—depend on population density. Others—including natural disasters and unusual weather—do not depend on population density. Acting separately or together, limiting factors determine the carrying capacity of an environment for a species. Limiting factors keep most natural populations somewhere between extinction and overrunning the planet.

Charles Darwin recognized the importance of limiting factors in shaping the history of life on Earth. As you will learn in Unit 5, the limiting factors we describe here produce the pressures of extinction and overrunning the planet.

What limiting factors do determine carrying capacity?

Vocabulary
limiting factor
density-dependent limiting factor
density-independent limiting factor

Taking Notes
Outline Make an outline using the green and blue headings in the lesson. Fill in details as you read to help you organize the information.

FIGURE 5–6 Limiting Factors Many different factors can limit population growth. Some of these factors depend on population density, while others do not. Infer How might each of these factors increase the death rate in a population?

Getting Started

Objectives
5.2.1 Identify factors that determine carrying capacity.
5.2.2 Identify the limiting factors that depend on population density.
5.2.3 Identify the limiting factors that do not depend on population density.

Student Resources
Study Workbooks A and B, 5.2 Worksheets
Spanish Study Workbook, 5.2 Worksheets
Lab Manual B, 5.2 Hands-On Activity Worksheet

Answers

FIGURE 5–6 Competition: organisms may not have enough resources to survive; Predation: organisms die when they are eaten; Parasitism and disease: organisms are killed; Natural disaster and unusual weather: organisms are killed or resources are diminished.

Teach for Understanding

ENDURING UNDERSTANDING The existence of life on Earth depends on interactions among organisms and between organisms and their environment.

GUIDING QUESTION What factors limit a population’s growth?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show their understanding of the factors that limit population growth. Have students make a T-Chart listing and describing limiting factors. One side of the T-chart should be labeled Density-Dependent Factors, and the other side labeled Density-Independent Factors.

Study Wkbks A/B, Appendix S30, T-Chart. Transparencies, GO15.
Lesson 5.2 • InterActive Art

Lead a Discussion

Have students recall from the previous lesson the four factors that affect population growth. (birthrate, immigration, death rate, emigration)

Ask How can competition affect the birthrate of a population? (If competition results in individuals not obtaining enough resources to reproduce, the birthrate of the population may decrease.)

Ask How can competition affect the death rate of a population? (If individuals cannot obtain enough resources to survive, the death rate may increase.)

Ask How can competition affect the rates of immigration and emigration? (If there is not much competition for the resources in an ecosystem, individuals from other ecosystems may move in, increasing immigration rate. If competition for resources is severe, the rate of emigration may increase as individuals seek other ecosystems in which to live.)

DIFFERENTIATED INSTRUCTION

L1 Special Needs Help students summarize ways in which competition can affect birthrate, immigration, death rate, and emigration in simple sentences, for example, “Competition can reduce birthrate.” Write each sentence on the board. Then, ask students to discuss details related to the main idea summarized in each of the sentences.

Density-Dependent Limiting Factors

What limiting factors depend on population density?

Density-dependent limiting factors operate strongly only when population density—the number of organisms per unit area—reaches a certain level. These factors do not affect small, scattered populations as much. Density-dependent limiting factors include competition, predation, herbivory, parasitism, disease, and stress from overcrowding.

Competition When populations become crowded, individuals compete for food, water, space, sunlight, and other essentials. Some individuals obtain enough to survive and reproduce. Others may obtain just enough to live but not enough to enable them to raise offspring. Still others may starve to death or die from lack of shelter. Thus, competition can lower birthrates, increase death rates, or both.

Competition is a density-dependent limiting factor, because the more individuals living in an area, the sooner they use up the available resources. Often, space and food are related to one another. Many grazing animals compete for territories in which to breed and raise offspring. Individuals that do not succeed in establishing a territory find no mates and cannot breed.

Competition can also occur among members of different species that are attempting to use similar or overlapping resources. This type of competition is a major force behind evolutionary change.

Predation and Herbivory The effects of predators on prey and the effects of herbivores on plants are two very important density-dependent population controls. One classic study focuses on the relationship between wolves, moose, and plants on Isle Royale, an island in Lake Superior. The graph in Figure 5–8 shows that populations of wolves and moose have fluctuated over the years. What drives these changes in population size?

Predator-Prey Relationships In a predator-prey relationship, populations of predators and prey may cycle up and down over time. Sometimes, the moose population on Isle Royale grows large enough that moose become easy prey for wolves. When wolves have plenty to eat, their population grows. As the wolf population grows, the wolves begin to kill more moose than are born. This causes the moose death rate to rise higher than its birthrate, so the moose population falls. As the moose population drops, wolves begin to starve. Starvation raises the wolves’ death rate and lowers their birthrate, so the wolf population also falls. When only a few predators are left, the moose death rate drops, and the cycle repeats.

Quick Lab

PURPOSE Students will be able to determine that competition affects plant growth.

MATERIALS bean seeds, 2 paper cups, potting soil, waterproof marker

SAFETY Students should wash their hands after planting the seeds.

PLANNING You may want to provide a tray or other waterproof surface on which students can place their cups. Remind them to control variables such as the amount of water and amount of sunlight the cups of seeds receive.

ANALYZE AND CONCLUDE

1. The seedlings in cup 15 will be smaller and less robust than those in cup 3. Some seedlings in cup 15 may die.
How Science Works

RESEARCH ON ISLE ROYALE

Isle Royale, an island in Lake Superior, is a National Park that has been the site of research on the interactions of wolf and moose populations for more than 50 years. It is considered an ideal site for research in the field of population biology because of its isolation. Wolves first moved into the Isle Royale ecosystem in the 1940s via an ice bridge. In the late 1950s, scientists began studying the interactions of the populations of moose and wolves; the study continues today. The long-term nature of the study has allowed scientists to learn not only about direct effects of predator-prey interactions on populations, but also to examine the impact of other factors affecting populations, such as changing pollution levels and environmental legislation.

Use Visuals

Have students examine Figure 5–8 to help them understand the effects of predator-prey relationships on population size.

Ask What general trends are shown in this graph? (An increase in the wolf population is usually accompanied by a decrease in the moose population. A decrease in the wolf population is usually accompanied by an increase in the moose population.)

Ask What factors other than the predator-prey relationship affected the size of these populations during the time period represented in the graph? (disease, the moose’s changing food supply)

DIFFERENTIATED INSTRUCTION

Struggling Students Make sure students understand that two separate sets of data are plotted on the graph. Point out the left and right vertical axes, which are numbered in different increments. Explain that the left vertical axis and the blue line represent the wolf population; the right vertical axis and the red line represent the moose population.

Advanced Students Have students work in a group to discuss trends they might expect to have occurred in the balsam fir population on Isle Royale over the time period represented in the graph. Ask them to share a brief summary of their discussion with the class.

Focus on ELL: Build Background

ALL SPEAKERS Have students use the Think-Pair-Share strategy to help them more fully comprehend density-dependent limiting factors. Pair beginning and intermediate speakers with advanced or advanced high speakers. Have students read the information about density-dependent limiting factors one factor at a time. After they read, suggest they discuss the factor and try to identify an example of it that they may have either seen or read about in the past. For example, for herbivory, some students may have seen an insect eating a plant leaf. Have pairs write down their examples and then share them with the class.

Study Wkbks A/B, Appendix S14, Think-Pair-Share.
Students should identify limiting factors, such as competition, predation, parasitism and disease, overcrowding, severe weather, and natural disasters. Students can go online to Biology.com to gather their evidence.

Parasitism and Disease  Parasites and disease-causing organisms feed at the expense of their hosts, weakening them and often causing disease or death. The ticks on the hedgehog in Figure 5–9, for example, can carry diseases. Parasitism and disease are density-dependent effects because the denser the host population, the more easily parasites can spread from one host to another.

If you look back at the graph in Figure 5–8, you can see a sudden and dramatic drop in the wolf population around 1980. At that time, a viral disease of wolves was accidentally introduced to the island. This virus killed all but 13 wolves on the island—and only three of the survivors were females. The removal of wolves caused moose populations to skyrocket to 2400. The densely packed moose then became infested with winter ticks that caused hair loss and weakness.

Stress From Overcrowding  Some species fight amongst themselves if overcrowded. Too much fighting can cause high levels of stress, which can weaken the body’s ability to resist disease. In some species, stress from overcrowding can cause females to neglect, kill, or even eat their own offspring. Thus, stress from overcrowding can lower birthrates, raise death rates, or both. It can also increase rates of emigration.

Density-Independent Limiting Factors

**What limiting factors do not typically depend on population density?**

**Density-independent limiting factors** affect all populations in similar ways, regardless of population size and density. **Unusual weather such as hurricanes, droughts, or floods, and natural disasters such as wildfires, can act as density-independent limiting factors.** In response to such factors, a population may “crash.” After the crash, the population may build up again quickly, or it may stay low for some time.

For some species, storms can nearly extinguish local populations. For example, thrips, aphids, and other insects that feed on leaves can be washed out by a heavy rainstorm. Waves whipped up by hurricanes can devastate shallow coral reefs. Extremes of cold or hot weather also can take their toll, regardless of population density. A severe drought, for example, can kill off great numbers of fish in a river, as shown in Figure 5–10.

**True Density Independence?**  Sometimes, however, the effects of so-called density-independent factors can actually vary with population density. On Isle Royale, for example, the moose population grew exponentially for a time after the wolf population crashed. Then, a bitterly cold winter with very heavy snowfall covered the plants that moose feed on, making it difficult for the moose to move around to find food.

### Visual Representation

**Mystery Clue**

What factors do you think could limit the size of a rabbit population?

**Check for Understanding**

**VISUAL REPRESENTATION**

Ask students to create a Concept Map showing how limiting factors affect populations.

**Study Wkbks A/B, Appendix S21, Concept Map. Transparencies, GO4.**

**ADJUST INSTRUCTION**

If students’ concept maps reveal they are struggling to understand limiting factors, ask them to review their concept maps in small groups. Within each group, have students review and revise their concept maps.
Density-independent limiting factors

Biotic factors include competition, predation, herbivory, parasitism, disease, stress from overcrowding, and pests or diseases that consume the population. These factors can severely limit a population's growth regardless of their size or density.

Controlling Introduced Species

In hydrilla’s natural environment, density-dependent population limiting factors keep it under control. Perhaps plant-eating insects or fishes devour it. Or perhaps pests or diseases weaken it. Whatever the case, those limiting factors are not found in the United States. The result is runaway population growth!

Efforts at artificial density-independent control measures—such as herbicides and mechanical removal—offer only temporary solutions and are expensive. Researchers have spent decades looking for natural predators and pests of hydrilla. The best means of control so far seems to be an imported fish called grass carp, which view hydrilla as an especially tasty treat. These grass carp are not native to the United States. Only sterilized grass carp can be used to control hydrilla. Can you understand why?

Assess and RemEDIATE

**Build Science Skills**

Have students study Figure 5–10. Then, ask them to make inferences about the impact of the drought on a variety of populations in this ecosystem. For example, a population of water plants might become overcrowded as a result of a decrease in the water level of the river. Or, plants along the riverbank might dry out and die, limiting nesting places for some birds. Have volunteers discuss their inferences with the class.

**EVALUATE UNDERSTANDING**

Name a type of ecosystem, such as forest, pond, or grassland. Have a volunteer identify one population of living things typically found in that ecosystem. Then, ask volunteers to describe as many specific limiting factors affecting the population as possible. As each limiting factor is identified, have students categorize it as density-dependent or density-independent. Then, have students complete the 5.2 Assessment.

**REMEDIATION SUGGESTION**

Struggling Students Provide students with a few examples of how the drought pictured in Figure 5–10 might have affected populations in the ecosystem. Then, have them work in pairs to identify additional examples.

**Assessment Answers**

1a. a factor that controls the growth of a population

1b. by determining the carrying capacity of environments for populations

2a. Answers may vary: Factors include competition, predation, herbivory, parasitism, disease, stress from overcrowding.

2b. Competition between individuals increases as population size increases.

3a. a factor that affects populations regardless of their size or density

3b. Sample answer: A drought could limit food supplies outside the cave. A flood could fill the cave with water. A snowstorm could block the entrance to the cave.

4. Biotic factors include competition, predation, and parasitism and disease. Unusual weather and natural disasters are abiotic factors.

**FIGURE 5–10 Effects of a Severe Drought on a Population**

Dead fish lie rotting on the banks of the once-flowing Paraná de Manaquiri River in Brazil.

**DIFFERENTIATED INSTRUCTION**

Struggling Students Have students work in small groups to brainstorm a list of specific density-independent limiting factors if they are struggling to answer Question 3b.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.
5.3 Human Population Growth

Getting Started

Objectives
5.3.1 Discuss the trend of human population growth.
5.3.2 Explain why population growth rates differ in countries throughout the world.

Student Resources
Study Workbooks A and B, 5.3 Worksheets
Spanish Study Workbook, 5.3 Worksheets

Build Background

Write the following questions on the board:
• What limiting factors affect the human population?
• How are these limiting factors similar to or different than the limiting factors affecting other populations?

For corresponding lesson in the Foundation Edition, see pages 117–119.

Exponential Human Population Growth

As civilization advanced, life became easier, and the human population began to grow more rapidly. That trend continued through the Industrial Revolution in the 1800s. Food supplies became more reliable, and essential goods could be shipped around the globe. Several factors, including improved nutrition, sanitation, medicine, and healthcare, dramatically reduced death rates. Yet, birthrates in most parts of the world remained high. The combination of lower death rates and high birthrates led to exponential growth, as shown in Figure 5–11.

The Predictions of Malthus

As you’ve learned, this kind of exponential growth cannot continue forever. Two centuries ago, this problem troubled English economist Thomas Malthus. Malthus suggested that only war, famine, and disease could limit human population growth. Can you see what Malthus was suggesting? He thought that human populations would be regulated by competition (war), limited resources (famine), parasitism (disease), and other density-dependent factors. Malthus’s work was vitally important to the thinking of Charles Darwin.

Historical Overview

The human population, like populations of other organisms, tends to increase. The rate of that increase has changed dramatically over time. For most of human existence, the population grew slowly because life was harsh. Food was hard to find. Predators and diseases were common and life-threatening. These limiting factors kept human death rates very high. Until fairly recently, only half the children in the world survived to adulthood. Because death rates were so high, families had many children, just to make sure that some would survive.

Exponential Human Population Growth

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The Predictions of Malthus

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Teach for Understanding

ENDURING UNDERSTANDING The existence of life on Earth depends on interactions among organisms and between organisms and their environment.

GUIDING QUESTION How is the human population growing?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show their understanding of human population growth. Have students work in small groups to write a short paragraph explaining why age structure is a key characteristic demographers use when making predictions about human population growth.
World Population Growth Slows So what is happening to human population growth today? Exponential growth continued up to the second half of the twentieth century. The human population growth rate reached a peak around 1962–1963, and then it began to drop. The size of the global human population is still growing rapidly, but the rate of growth is slowing down.

It took 123 years for the human population to double from 1 billion in 1804 to 2 billion in 1927. Then it took just 33 years for it to grow by another billion people. The time it took for the population to increase each additional billion continued to fall until 1999, when it began, very slowly, to rise. It now takes longer for the global human population to grow by 1 billion than it did 20 years ago. What has been going on?

Patterns of Human Population Growth

EXPLAIN Why do population growth rates differ among countries?

Scientists have identified several social and economic factors that affect human population growth. The scientific study of human populations is called demography. Demography examines characteristics of human populations and attempts to explain how those populations will change over time. Population growth rates, death rates, and the age structure of a population help predict why some countries have high growth rates while other countries grow more slowly.

In Your Notebook Explain how the size of the global human population can increase while the rate of growth decreases.

Quick Facts

A GLOBAL POPULATION

International migration plays an increasingly significant role in the population growth of many countries, particularly as fertility declines. According to a United Nations report (World Population Prospects, The 2006 Revision, Population Division, Department of Economic and Social Affairs), the net number of international migrants to more developed regions over the period from 2005 to 2050 is projected to be 103 million, which counterbalances the projected number of deaths over births (74 million) for the same period. The countries with the highest net levels of migrants entering the population annually are projected to be: the United States (1.1 million), Canada (3.0 million), Germany (1.0 million), Italy (0.9 million), the United Kingdom (1.0 million), Spain (1.2 million), and Australia (1.0 million). On the contrary, the countries with the highest levels of net emigration are projected to be: China (1.3 million), Mexico (0.4 million), India (0.2 million), the Philippines (0.1 million), Pakistan (0.1 million), and Indonesia (0.1 million).

Teach

Connect to Math

Have students examine the graph of human population growth shown in Figure 5–11.

Ask Does this graph have a shape more like exponential growth or logistic growth? (Exponential growth)

Ask The text states that the human population growth rate has started to slow down. How does this apply to what you have already learned about logistic growth? (Logistic growth has three phases. During Phase I, growth is exponential; during Phase II, growth slows; and during Phase III, the population size stays fairly steady around a fixed level. Human population growth is showing a slowdown from exponential growth; it may be moving into Phase II of logistic growth.)

DIFFERENTIATED INSTRUCTION

Struggling Students Help students locate and review the information and graphs in Lesson 5.1 showing exponential and logistic growth. Then, have them use these graphs to help them answer the questions above.

Focus on ELL: Access Content

INTERMEDIATE, ADVANCED, AND ADVANCED HIGH SPEAKERS Have students use a Main Ideas and Details Chart to organize the information in this lesson. Point out that Key Concepts within the lesson can serve as the main ideas. As they read the text associated with each concept, have them add details. Intermediate speakers can use words or short phrases to record details; encourage advanced students to use complete sentences; require advanced high students to use complete, complex sentences. At the conclusion of the lesson, have students share aloud details from their charts.

Study Wkbks A/B, Appendix S28, Main Ideas and Details Chart. Transparencies, GO13.

Answers

IN YOUR NOTEBOOK The growth rate of the human population has not reached zero. The population is still growing, just not as rapidly.
**Use Visuals**

Students can use Figure 5–13 to see how age structure is related to population growth.

**Ask** What overall pattern do you see in the age-structure diagram of Guatemala’s population? (Moving from youngest to oldest, every subgroup of the population is smaller than the one before it.)

**Ask** How does this compare to the overall pattern in the age-structure diagram of the U.S. population? (The age-structure diagram for the U.S. does not exhibit the same pattern. Instead, in the subgroups for individuals up to age 55, there are approximately equal numbers in each subgroup.)

**Ask** What does this difference in age structure imply about future growth of each population? (The number of women in Guatemala who are in the age group likely to bear children will increase every year, meaning population growth will increase every year. In the United States, the number of women in the age group likely to bear children will stay fairly consistent, implying that population growth will stay fairly steady.)

**DIFFERENTIATED INSTRUCTION**

**L3 Advanced Students** Have students make an age-structure diagram for an imaginary country with a population with a negative growth rate. Then, have students research to identify actual countries that have negative growth rates and projected population declines between the present time and 2050. Have students share what they learn with the class.

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**The Demographic Transition**

Human societies had equally high birthrates and death rates during most of history. But over the past century, population growth in the United States, Japan, and much of Europe slowed dramatically. Demographers developed a hypothesis to explain this shift. According to this hypothesis, these countries have completed the demographic transition, a dramatic change from high birthrates and death rates to low birthrates and death rates. The demographic transition is divided into three stages, as shown in Figure 5–12. To date, the United States, Japan, and Europe have completed the demographic transition. Parts of South America, Africa, and Asia are passing through Stage II. (The United States passed through Stage II between 1790 and 1910.) A large part of ongoing human population growth is happening in only ten countries, with India and China in the lead. Globally, human population is still growing rapidly, but the rate of growth is slowing down. Our J-shaped growth curve may be changing into a logistic growth curve.

**Age Structure and Population Growth**

To understand population growth in different countries, we turn to age-structure diagrams. Figure 5–13 compares the age structure of the U.S. population with that of Guatemala, a country in Central America. In the United States, there are nearly equal numbers of people in each age group. This age structure predicts a slow but steady growth rate for the near future. In Guatemala, on the other hand, there are many more young children than teenagers, and many more teenagers than adults. This age structure predicts a population that will double in about 30 years.

**FOLLOW-UP PROBES**

**Ask** Why is an age-structure diagram more useful than a total population count in projecting a population’s future growth rate? Explain. (A total population count doesn’t distinguish ages and gender, and so can’t really be used to predict increases and decreases in the population.)

**ADJUST INSTRUCTION**

If responses indicate students do not understand why age structure is an important tool for projecting future population growth, remind them that only females in a certain age range can have children. Explain that an age-structure diagram allows scientists to see how many women will be within that age group both now and in the near future.

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**Check for Understanding**

**FIGURE 5–13 Comparison of Age Structures** These diagrams compare the populations of the United States and Guatemala. Notice the difference in their x-axis scales. Analyze Data How do the two countries differ in the percentages of 10–14-year-olds in their populations?

**FIGURE 5–12 The Demographic Transition** Human birthrates and death rates are high for most of history (Stage I). Advances in nutrition, sanitation, and medicine lead to lower death rates. Birthrates remain high for a time, so births greatly exceed deaths (Stage II), and the population increases exponentially. As levels of education and living standards rise, families have fewer children and the birthrate falls (Stage III), and population growth slows. The demographic transition is complete when the birthrate meets the death rate, and population growth stops.

**Answers**

**FIGURE 5–13** Guatemala has a higher percentage of 10–14-year-olds in its population than does the United States.
**Assess and Remediate**

**EVALUATE UNDERSTANDING**

Ask volunteers to describe how the human population growth rate has changed over time. Then, have students complete the 5.3 Assessment.

**REMEDICATION SUGGESTION**

- **Struggling Students** If students have difficulty answering Question 2b, suggest they review Figure 5–12 and discuss it with a partner.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

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**Future Population Growth**

To predict how the world’s human population will grow, demographers consider many factors, including the age structure of each country and the effects of diseases on death rates—especially AIDS in Africa and parts of Asia. Current projections suggest that by 2050 the world population will reach 9 billion people. Will the human population level out to a logistic growth curve and become stable? This may happen if countries that are currently growing rapidly complete the demographic transition.

Current data suggest that global human population will grow more slowly over the next 50 years than it grew over the last 50 years. But because the growth rate will still be higher than zero in 2050, our population will continue to grow. In the next chapter, we will examine the effect of human population growth on the biosphere.

**Assessment Answers**

**1a.** For tens of thousands of years, the human population grew very slowly. Then, about 500 years ago, the population started to grow exponentially and increased dramatically. The growth rate slowed in the second half of the twentieth century; the population is still growing, but at a slower rate.

**1b.** Harsh living conditions resulted in high death rates that occurred through most of human history. Rapid population growth occurred when advances, such as improved nutrition, healthcare, and sanitation, decreased the death rate.

**2a.** Different countries have different birthrates, death rates, and age structures.

**2b.** The demographic transition occurs in three stages. In Stage I, a country has a high birthrate and a high death rate. In Stage II, the death rate drops, but the birthrate remains high. In Stage III, the birthrate drops to meet the death rate. The population growth of a country slows after it has completed the demographic transition.

**2c.** Sample answer: Yes, age-structure diagrams allow scientists to determine if the number of individuals likely to have children will increase or decrease in the future.

**3.** Sample answer: The age structure shown in the diagram would lead me to predict that birthrates will remain fairly constant. There will also be an increase in the percentage of individuals in the oldest age groups. These individuals can contribute a great deal to society, but may also increase the demand for healthcare.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab The Growth Cycle of Yeast described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Remind students to handle glass items with care and follow your direction about disposal of lab materials. Have them wash their hands with soap and warm water when they complete the lab.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 120.

BACKGROUND QUESTIONS

a. Carrying capacity is the maximum number of a species that a particular environment can support.

b. Sample answer: In Phase 1 of logistic growth, resources are unlimited and the population grows rapidly. In Phase 2, the rate of growth slows down. In Phase 3, the rate of growth drops to zero and the size of the population levels off.

c. Sample answers: The number of births is equal to the number of deaths, or there were no births or deaths, or as many people moved into the population as moved out.

d. Sample answer: The small amount of rain could be classified as a density-dependent factor because the blades had to compete for this resource. (The heat and sunlight were not density-dependent factors because each blade of grass received about the same amount of heat and light.)

PRE-LAB QUESTIONS

1. Sample answer: The grape juice contains nutrients that the yeast cells need to grow and reproduce.

2. Sample answer: With low power, the field of view is larger, which makes finding the cells easier. With high power, the magnification is greater, which makes counting the cells easier.

3. 21 x 10 or 210 yeast cells

4. Some students may assume that the nutrients are sufficient to sustain rapid growth through Day 7. Others may assume that the nutrients will begin to limit and slow down growth by Day 7.
Density-independent limiting factors affect all populations in similar ways, regardless of population size and density. Unusual weather such as hurricanes, droughts, or floods, and natural disasters such as wildfires, can act as density-independent limiting factors.

Density-dependent limiting factors operate strongly when population density reaches a certain level. Density-dependent limiting factors include competition, predation, herbivory, parasitism, disease, and stress from overcrowding.

The factors that can affect population size are the birthrate, the death rate, and the rate at which individuals enter or leave the population. Under ideal conditions with unlimited resources, a population will grow exponentially.

Logistic growth occurs when a population's growth slows and then stops, following a period of exponential growth. Phase I, during which the population grows exponentially; Phase II, during which population growth slows; and Phase III, during which population growth stops and the population size remains fairly constant.

The human population, like populations of other organisms, tends to increase. The rate of that increase has changed dramatically over time.

Birthrates, death rates, and the age structure of a population help predict why some countries have high growth rates while other countries grow more slowly.

5.2 Limits to Growth

Density-dependent limiting factors operate strongly when population density reaches a certain level. Density-dependent limiting factors include competition, predation, herbivory, parasitism, disease, and stress from overcrowding.

Activity 5.2

Density-dependent limiting factors operate strongly when population density reaches a certain level. Density-dependent limiting factors include competition, predation, herbivory, parasitism, disease, and stress from overcrowding.

Performance Tasks

SUMMATIVE TASK Have students imagine that an advance in medical technology immediately doubles the average life span of residents of the United States, but does not affect the age of reproduction. Have them use the age-structure diagram of the U.S. in Figure 5-12 as a starting point for preparing age-structure diagrams for 25 and 50 years in the future reflecting the change in life span. Then, have students write a paragraph describing how—or if—the introduction of the medical technology would change the size, density, growth rate, age structure, birthrate, and death rate of the human population in the U.S.

TRANSFER TASK Have students use what they have learned about characteristics of populations, limiting factors, carrying capacity, and human population growth to write a science fiction story set in the future, at the time when the human population reaches Earth's carrying capacity. Students' stories should be creative, but scientifically accurate. Remind them to include information about limiting factors acting on the human population, a scientifically accurate definition of carrying capacity, and accurate information from the text about human population growth.

Answers

THINK VISUALLY

Students' tables should include a description of Phase I, during which the population grows exponentially; Phase II, during which population growth slows; and Phase III, during which population growth stops and the population size remains fairly constant.

Answers

THINK VISUALLY

Students' tables should include a description of Phase I, during which the population grows exponentially; Phase II, during which population growth slows; and Phase III, during which population growth stops and the population size remains fairly constant.
Lesson 5.1

UNDERSTAND KEY CONCEPTS
1. b  2. c  3. b  4. b  5. b
6. Immigration is the movement of individuals into a population; emigration is the movement of individuals out of a population.
7. Students’ graphs should resemble the graphs shown in Figure 5–4.
8. Logistic growth occurs when a population’s growth slows following a period of exponential growth and then stops at or near the carrying capacity.
9. Carrying capacity is the maximum number of individuals of a particular species a particular environment can support. Examples will vary.

THINK CRITICALLY
10. The carrying capacity of a city’s roads and the carrying capacity of an ecosystem are similar, because they are both limited by the resources available. In the case of a city’s roads, the carrying capacity depends on factors such as the number and width of roads and the number of intersections. In an ecosystem, the carrying capacity depends on factors such as the amount of space and food.

Lesson 5.2

UNDERSTAND KEY CONCEPTS
11. a  12. b
13. Increasing the availability of a limiting nutrient would increase the carrying capacity of the pond.
14. If two species are competing for the same resources, the one that is better at competing for the resource will have a higher birthrate than the other, and may eventually displace the other species. Students may also say that species may adapt by using different resources.
15. A predator-prey relationship can be a mechanism of population control for both species. The population size of predators is limited by the number of prey available to eat. In turn, the number of prey is limited by the predation.
16. Parasites are a limiting factor because they feed on host organisms, weakening the host and often causing disease or death. Parasitism is considered a density-dependent limiting factor because the more crowded a population becomes, the more easily parasites can spread from one individual to another.

THINK CRITICALLY
17. If there is a sudden increase in food for a population of prey, the prey population will increase. This means there will be more food for the predators, which will then also increase.
18. A contagious virus spreads more easily in crowded conditions; it is considered a density-dependent factor.
19. In most cases, it will have a greater impact on populations in a small ecosystem. A small population, like those found in small ecosystems, will be more susceptible to serious damage from a density-independent factor such as a storm or a flood.
20. In both parasite-host relationships and predator-prey relationships, the two species involved limit one another’s population growth.
21. Sample answer: If the water level drops, the fish population’s density increases. This makes the fish population more susceptible to density-dependent limiting factors.
Lesson 5.3

UNDERSTAND KEY CONCEPTS

22. d
23. a
24. The human population began growing more rapidly 500 years ago due to conditions that made survival more likely, thereby decreasing the death rate. Reliable food supply, improved sanitation, and better medical care are three factors that caused this change.
25. Studies of populations around the world use the concept of the demographic transition to help make predictions about future growth; they show which human populations have stabilized and which are still increasing.
26. Populations with nearly equal numbers of people in each age group will likely have a slow but steady growth rate for the near future. Populations with many more young people than adults will likely grow at a rapid rate.
27. Malthus suggested war, famine, and disease would limit the human population.

THINK CRITICALLY

28. A town populated mainly with senior citizens would have a population growth curve showing a decreasing population, because the death rate would exceed the birthrate. A town populated by newly married couples would have a population growth curve showing a population increase, because the birthrate would exceed the death rate.
29. He/she would need to learn the birthrate and death rate for the country over the past few decades—indications of whether the rates are generally increasing or decreasing.
Connecting Concepts

USE SCIENCE GRAPHICS

30. Observe When did the world population reach 1 billion people? When did it reach 6 billion?

31. Interpret Tables Describe the trend in population growth since the 1-billion-people mark.

WRITE ABOUT SCIENCE

32. Explanation Write a paragraph about the human population. Include the characteristics of a population, factors that affect its size, and changes in the size of the population from about 500 years ago to the present. Give a projection of how large the world population might be in 2050 and of how the growth rate in 2050 might compare to that in 2000. (Hint: Outline your ideas before you begin to write.)

33. Assess the Choose a specific organism and explain how the population of that organism depends on a number of factors that may cause it to increase, decrease, or remain stable in size.

ASSessment

Analyzing Data

34. Interpret Graphs In which of the following years was the rabbit population density in South Australia most dense?
   a. 1936  c. 1975
   b. 1952  d. 2000

35. Infer European rabbit fleas were introduced in the late 1960s to help spread the effects of the rabbit disease myxomatosis. Based on the graph, what can you infer about the rabbit population after the fleas were introduced?
   a. The rabbit birthrate increased.
   b. The rabbit death rate increased.
   c. The rabbit death rate decreased.
   d. The fleas had no effect on the rabbit population.

ANSWERS

34. b
35. b
Standardized Test Prep

Multiple Choice
1. The movement of individuals into an area is called
   A immigration.
   B emigration.
   C population growth rate.
   D population density.
2. All other things being equal, the size of a population will decrease if
   A birthrate exceeds the death rate.
   B immigration rate exceeds emigration rate.
   C death rate exceeds birthrate.
   D birthrate equals death rate.
3. Which of the following is NOT an example of a density-dependent limiting factor?
   A natural disaster
   B predator
   C competition
   D disease
4. A population like that of the United States with an age structure of roughly equal numbers in each of the age groups can be predicted to
   A grow rapidly over a 30-year-period and then stabilize.
   B grow little for a generation and then grow rapidly.
   C fall slowly and steadily over many decades.
   D show slow and steady growth for some time into the future.
5. In the presence of unlimited resources and in the absence of disease and predation, what would probably happen to a bacterial population?
   A logistic growth
   B exponential growth
   C endangerment
   D extinction
6. Which of the following statements best describes human population growth?
   A The growth rate has remained constant over time.
   B Growth continues to increase at the same rate.
   C Growth has been exponential in the last few hundred years.
   D Birthrate equals death rate.
7. Which of the following refers to when a population’s birthrate equals its death rate?
   A limiting factor
   B carrying capacity
   C exponential growth
   D population density

Questions 8–9
Use the graph below to answer the following questions.

Logistic Growth

8. Which time interval(s) in the graph shows exponential growth?
   A D and E
   B A and B
   C C and D
   D E only

9. Which time interval(s) in the graph depicts the effects of limiting factors on the population?
   A A only
   B A and B
   C C, D, and E
   D C and D

Open-Ended Response
10. When a nonnative species is imported into a new ecosystem, the population sometimes runs wild. Explain why this might be the case.

Sample answer: The new ecosystem may lack the limiting factors present in the species’ native ecosystem, allowing the population to grow exponentially. Introduced organisms may destroy populations of native organisms, and in doing so, may further reduce their competition. It can be very difficult, or impossible, to remove a species once it has been introduced without upsetting the rest of the ecosystem.

If You Have Trouble With . . .

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
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<tbody>
<tr>
<td>See Lesson</td>
<td>5.1</td>
<td>5.1</td>
<td>5.2</td>
<td>5.3</td>
<td>5.1</td>
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</tbody>
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Test-Taking Tip

**INTERPRET GRAPHS**
Tell students to carefully review a graph before they answer any questions that relate to it. Make sure students read the title, axis labels, and any other information on the graph. Suggest they mentally summarize what the graph shows before reading any questions. Once they are sure they fully understand the graph, then suggest they read and answer the questions.
Connect to the Big Idea

Have students examine the photograph of Earth from space showing the pattern of lights on the planet. Ask students what a comparison of North and South America tells them about the human activities on the two continents. (Sample answer: Lights are much more prevalent in North America, which indicates greater development than in South America.) Ask students what the difference tells them about energy use on the two continents. (Sample answer: More lights suggest humans are using much more energy in North America than in South America.) Ask where else the photo suggests humans are using a large amount of energy. (throughout Europe, in India, in eastern China, and in Japan) Discuss with students how energy use might affect the ecology of a region. Then, have students anticipate the answer to the question, How have human activities shaped local and global ecology?

Have students read over the introduction to the Chapter Mystery and predict what happened to the trees on Easter Island. Use their predictions to help them start connecting the Chapter Mystery to the Big Idea of Interdependence in Nature.

Have students preview the chapter vocabulary terms using the Flash Cards.

CHAPTER 6

Humans in the Biosphere

Interdependence in Nature

How have human activities shaped local and global ecology?

(Viewed from space, the lights of human settlement are obvious. The brightest areas are the most developed but not necessarily the most populated. Development is one way in which humans, who today number over 6.5 billion, have affected the biosphere.)

Understanding by Design

In Chapter 6, students examine the wise use of resources, the importance of biodiversity, and the need to meet ecological challenges. The graphic organizer at the right shows how the Big Idea, Essential Question, and Guiding Questions help frame students’ exploration of the Unit 2 Enduring Understanding that the existence of life on Earth depends on interactions among organisms and between organisms and their environment.

Performance Goals

In Chapter 6, students will interpret information in maps, graphs, and diagrams. They will also analyze a day’s worth of trash to see which items can be reused, recycled, or composted. At the end of the chapter, students will apply their knowledge by writing a magazine article about an environmental activist.

NATIONAL SCIENCE EDUCATION STANDARDS

Unifying Concepts and Processes

I, II, III, IV

Content


Inquiry

A.1.b, A.1.c, A.2.a, A.2.d
Moving the Moai
Easter Island is a tiny speck of land in the vast Pacific Ocean off the coast of Chile with a harsh tropical climate. The original islanders, who called themselves Rapa Nui, came from Polynesia. They carved hundreds of huge stone statues called moai (moh eye). Starting around 1200 A.D., the Rapa Nui somehow moved these mysterious statues, each of which weighed between 10 and 14 tons, from quarries to locations around the island. Nearly all theories about this process suggest that strong, large logs were necessary to move the moai. Yet by the time Europeans landed on the island in 1722, there was no sign of any trees large enough to provide such logs. What had happened? As you read this chapter, look for clues about the interactions of the Rapa Nui with their island environment. Then, solve the mystery.

Never Stop Exploring Your World. The mystery of the moving Moais is just the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

What’s Online
Extend your reach by using these and other digital assets offered at Biology.com.

Chapter Mystery
Students go online and look into the disappearance of large trees on Easter Island.

Untamed Science Video
The Untamed Science crew go behind the scenes to uncover critical research and conservation programs in progress at the Houston Zoo.

Art in Motion
Students watch an animation of biological magnification.

Data Analysis
Students collect virtual biodiversity data from two sites and use this data to calculate a biodiversity index for the sites.

Art Review
Students review threats to biodiversity in this drag-and-drop activity.

Visual Analogy
Explore ecological footprints through this visual analogy.
Getting Started

Objectives
6.1.1 Describe human activities that can affect the biosphere.
6.1.2 Describe the relationship between resource use and sustainable development.

Student Resources
Study Workbooks A and B, 6.1 Worksheets
Spanish Study Workbook, 6.1 Worksheets

Activate Prior Knowledge
Describe a well-known natural area, such as a forest preserve or wetlands, in or near the students’ community. Have students imagine that a new housing development will be built there. Have them identify positive and negative impacts of such a project. (positives: new jobs, new houses; negatives: loss of trees, displaced animals)

Discuss with students which “mammalian stowaways” likely came to the island on ships. Then, discuss how introducing new organisms to the island ecosystem may have affected the native species. Students can go online to Biology.com to gather their evidence.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES
I, III

CONTENT
C.4.d, C.4.e, C.5.e, F.3, F.4, F.5, F.6

INQUIRY
A.1.b, A.2.a

A Changing Landscape

THINK ABOUT IT
The first humans to settle Hawaii came from Polynesia about 1600 years ago. These island people had customs that protected the natural resources of their new home. For example, they were prohibited from catching certain fish during spawning season and, for every coconut palm tree cut down, they had to plant two palms in its place. But Hawaiians did not treat their islands entirely like nature reserves. They cut trees to plant farms, and they introduced nonnative plants, pigs, chickens, dogs, and rats. This combination drove many native plant and animal species to extinction. Yet for centuries Hawaii’s ecosystems provided enough fresh water, fertile soil, fish, and other resources to keep the society self-sufficient. What happened next is a lesson on managing limited resources—a lesson that is as important today as it was over 1000 years ago.

The Effect of Human Activity
How do our daily activities affect the environment?
Beginning in the late 1700s, new waves of settlers arrived in Hawaii. These people did not seem to understand the limits of island ecosystems. They imported dozens more plants and animals that became invasive pests. They cleared vast tracts of forest to grow sugar cane, pineapples, and other crops that required lots of water. And as the island’s human population grew, they converted untouched land for other uses, including housing and tourism, as shown in Figure 6–1.

The effect of these activities on Hawaii’s ecosystems and its human inhabitants offers a window onto a globally important question: What happens when a growing human population does not adequately manage natural resources that are both vital and limited?

FIGURE 6–1 The Lesson of Hawaii
Kalalau Valley along the Na Pali coast of Kauai looks almost untouched by humans. In contrast, Waikiki Beach on the island of Oahu is surrounded by built-up areas that support tourism.

Teach for Understanding

ENDURING UNDERSTANDING
The existence of life on Earth depends on interactions among organisms and between organisms and their environment.

GUIDING QUESTION
How does human activity affect the environment?

EVIDENCE OF UNDERSTANDING
After completing this lesson, give students the following assessment to show their understanding of the difference between renewable and nonrenewable resources. Ask students to each make a list of all the renewable resources and nonrenewable resources they use in a typical day. Have volunteers share their lists with the class.
Humans, like all forms of life, rely on Earth’s life-support systems. And like all other organisms, we affect our environment when we obtain food, eliminate waste products, and build places to live. The effects of these activities can be most obvious on islands such as Hawaii because of their small size. Living on an island also can make people aware of limited resources and of an area’s carrying capacity for humans because anything not available locally must be brought in from far away.

Most of us who live on large continents, however, probably don’t think of land, food, and water as limited resources. In the past, environmental problems were local. There was always new land to settle and new sources of food and water. But today human activity has used or altered roughly half of all the land that’s not covered with ice and snow. Some people suggest that as the global population reaches 7 billion people, we may be approaching the carrying capacity of the biosphere for humans. **Humans affect regional and global environments through agriculture, development, and industry in ways that have an impact on the quality of Earth’s natural resources, including soil, water, and the atmosphere.**

### In Your Notebook  Explain how Earth is like an island.

**Agriculture**  Agriculture is one of the most important inventions in human history. A dependable supply of food that can be stored for later use enabled humans to gather in settlements that grew into towns and cities. Settlements, in turn, encouraged the growth of modern civilization—government, laws, writing, and science. Modern agricultural practices have enabled farmers to double world food production over the last 50 years. **Monoculture**, for example, is the practice of clearing large areas of land to plant a single highly productive crop year after year, like the soybeans in Figure 6–2. Monoculture enables efficient sowing, tending, and harvesting of crops using machines. However, providing food for nearly 7 billion people impacts natural resources, including fresh water and fertile soil. Fertilizer production and farm machinery also consume large amounts of fossil fuels.

**FIGURE 6–2**  **Monoculture**  This farmer is using a tractor to plow a large field of soybeans.

**Apply Concepts**  How has agriculture helped shape civilization?

### Lead a Discussion

Call on a student to define *carrying capacity*, a concept students learned about in Chapter 5. Then, read aloud the sentence in the text that suggests we may be approaching the carrying capacity for humans in the biosphere. Talk about whether students think that number is being reached or not. Encourage them to express their opinions, though challenge any statements that aren’t backed by evidence.

### DIFFERENTIATED INSTRUCTION

#### Less Proficient Readers  Before discussing the biosphere’s carrying capacity for humans, make sure students understand the three main ways humans affect regional and global environments. Read the bolded Key Concept statement aloud, and then write the three categories on the board: Agriculture, Development, Industry. Call on students to describe how specific examples of each can impact the quality of Earth’s natural resources. Make sure students know that the ways these human activities affect environments are not always bad.

### BUILD Vocabulary

**PREFIXES**  The prefix mono- in *monoculture* means “one, alone, single.” Monoculture is the practice of planting a single productive crop, year after year.

### Quick Lab

**PURPOSE**  Students will analyze the types of dry trash generated during a normal day and evaluate how the amount of trash produced could have been reduced.

**MATERIALS**  gloves; large trash bags, boxes, or bins

**SAFETY**  Make sure students wear gloves when sorting trash. Caution them to be careful when handling glass or metal items.

**PLANNING**  Provide trash bags to students the day before they complete the lab. Encourage them to start collecting their own trash as soon as they start their day. Reinforce that they are collecting *only* their own trash. Discuss the types of dry trash students should collect, including bottles, cans, plastic containers, packaging, and various types of paper.

**ANALYZE AND CONCLUDE**

1. **Answers will vary.**
2. **Sample answer:** Most of the trash goes to a landfill. Some items are recycled. Landfills take space from natural habitats for living things. Chemicals that leak from landfills can contaminate water, and if burned, trash releases greenhouse gases. Animals mistaking trash for food may eat it and become ill.
3. **Sample answer:** I can recycle more items, reuse some materials instead of throwing them away, and stop buying items that are heavily packaged.

Answers

**FIGURE 6–2**  Agriculture enabled humans to gather in settlements that grew into towns and cities. Settlements, in turn, encouraged the growth of modern civilization.

**IN YOUR NOTEBOOK**  Sample answer: Earth is like an island because the resources here are finite—we can’t get water or soil from anywhere else. It’s also like an island because humans can’t leave to live anywhere else.
Focus on ELL: Access Content

INTERMEDIATE AND ADVANCED SPEAKERS
Ask students to create a Compare/Contrast Table with three columns and three rows. Have them label each row as follows: Agriculture, Development, and Industrial Growth. Then, have them label the second and third columns Positive Effects and Negative Effects. Ask them to fill in the table with a summary statement about the negative and positive effects of each activity. Students can use their charts when participating in discussion and for review.

Study Wkbks A/B, Appendix S20, Compare/Contrast Table. Transparencies, GO3.

Answers

FIGURE 6–3 Sample answer: Wetlands filter water, and provide a habitat for many kinds of organisms.

IN YOUR NOTEBOOK Sample answer: The air I breathe, the water I drink, and the oil used to make the gasoline burned in our car are three examples.

Teach continued

Use Visuals
Have students compare the photo of the wetlands in Figure 6–3 with the inset photo of the same area as farmland.

Ask Why do you think The Wetlands Initiative would restore this area as wetlands? (Restoring it as wetlands provides wildlife habitat and a natural filter for the area’s water.)

Ask How is this restoration an example of sustainable development? (Sample answer: Sustainable development provides for human needs while preserving the ecosystem. Restoring the wetlands provides humans with clean drinking water while preserving the regional ecosystem.)

DIFFERENTIATED INSTRUCTION

ELL Advanced Students Have interested students research The Wetlands Initiative and report what they learn to the class. For example, what is the goal of the project? Who funds the project? What successes have they had? What challenges?

FIGURE 6–3 Ecosystem Services
Hopper Marsh is one of the wetlands controlled by The Wetlands Initiative—an organization dedicated to protecting and restoring Illinois’s wetlands. The area, originally drained for farming in 1900, is shown in the inset before its 2003 restoration. Apply Concepts: What ecological services do wetlands provide?

Sustainable Development

What is the relationship between resource use and sustainable development?

In the language of economics, goods are things that can be bought and sold, that have value in terms of dollars and cents. Services are processes or actions that produce goods. Ecosystem goods and services are the goods and services produced by ecosystems that benefit the human economy.

Ecosystem Goods and Services Some ecosystem goods and services—like breathable air and drinkable water—are so basic that we often take them for granted. Healthy ecosystems provide many goods and services naturally and largely free of charge. But, if the environment can’t provide these goods and services, society must spend money to produce them. In many places, for example, drinkable water is provided naturally by streams, rivers, and lakes, and filtered by wetlands like the one in Figure 6–3. But if water sources or wetlands are polluted or damaged, water quality may fail. In such cases, cities and towns must pay for mechanical or chemical treatment to provide safe drinking water.

Check for Understanding

ONE-MINUTE RESPONSE
Write the following question on the board, and give students about a minute to write a quick response.

Clear cutting is the process of removing the majority of trees from a forest for human use. What might a sustainable alternative to clear cutting look like?

ADJUST INSTRUCTION
If student responses show a misunderstanding of sustainable development, remind them that their plan should provide for human needs (wood for building, paper, etc.) while protecting the forest ecosystem. Ask them to think about the question: How can you use trees for wood while still protecting forests? Have students volunteer their ideas.
Renewable and Nonrenewable Resources  Ecosystem goods and services are classified as either renewable or nonrenewable, as shown in Figure 6–4. A renewable resource can be produced or replaced by a healthy ecosystem. A single southern white pine is an example of a renewable resource because a new tree can grow in place of an old tree that dies or is cut down. But some resources are nonrenewable resources because natural processes cannot replenish them within a reasonable amount of time. Fossil fuels like coal, oil, and natural gas are nonrenewable resources formed from buried organic materials over millions of years. When existing deposits are depleted, they are essentially gone forever.

Sustainable Resource Use  Ecological science can teach us how to use natural resources to meet our needs without causing long-term environmental harm. Using resources in such an environmentally conscious way is called sustainable development. Sustainable development provides for human needs while preserving the ecosystems that produce natural resources.

What should sustainable development look like? It should cause no long-term harm to the soil, water, and climate on which it depends. It should consume as little energy and material as possible. Sustainable development must be flexible enough to survive environmental stresses like droughts, floods, and heat waves or cold snaps. Finally, sustainable development must be flexible enough to survive environmental stresses. It provides for human needs while preserving ecosystems as well as ecosystem goods and services. It must do more than just enable people to survive. It must help them improve their situation.

Assessment Answers

1a. Sample answer: Agriculture: benefit, food production; cost, impacts on fresh water and fertile soil. Development: benefit, higher standard of living; cost, production of lots of wastes. Industrial growth: benefit, conveniences of modern life; cost, requires lots of energy to produce and power products.

1b. Sample answer: More productive agricultural practices would increase a nation’s population since there would be more food available. However, it would likely worsen the nation’s environmental health.

2a. Sustainable development means using resources in an environmentally conscious way. It provides for human needs while preserving ecosystems that produce natural resources.

2b. Sample answer: Energy from the sun is renewable because it can be replaced (the sun will keep burning). However, natural processes cannot replenish oil supplies within a reasonable amount of time, so oil is a nonrenewable resource.

2c. Sample answer: If there were no wetlands to provide flood control, societies would have to build more dams and barriers to prevent excess water from flooding cities and agricultural land.

Write About Science

3. Answers will vary depending on the community. Students might mention the spread of housing developments, the building of malls and other shopping areas, and the construction of highways and then explain how these affect their local ecosystem by necessitating new sources of power and materials.
Getting Started

Objectives

6.2.1 Describe how human activities affect soil and land.
6.2.2 Describe how human activities affect water resources.
6.2.3 Describe how human activities affect air resources.

Student Resources

Study Workbooks A and B, 6.2 Worksheets
Spanish Study Workbook, 6.2 Worksheets
Lab Manual B, 6.2 Data Analysis Worksheet

Build Background

From a library, obtain a recording of Woody Guthrie’s Dust Bowl Ballads, and play the song “The Great Dust Storm” for students. Lyrics for this song can be found online. Explain that Guthrie, one of America’s great folksingers, lived during the “dust bowl” that occurred in the Great Plains during the 1930s. Describe the huge dust storms that occurred during the dust bowl, and point out the photo of a dust storm in Figure 6–5.

THINK ABOUT IT Our economy is built on the use of natural resources, so leaving those resources untouched is not an option. Humans need to eat, for example, so we can’t just stop cultivating land for farming. But the goods and services provided by healthy ecosystems are essential to life. We can’t grow anything in soil that has lost its nutrients due to overfarming. If we don’t properly manage agriculture, then, we may one day lose the natural resource on which it depends. So how do we find a balance? How do we obtain what we need from local and global environments without destroying those environments?

Soil Resources

Why is soil important, and how do we protect it?

When you think of natural resources, soil may not be something that comes to mind. But many objects you come into contact with daily rely on soil—from the grain in your breakfast cereal, to the wood in your home, to the pages of this textbook. Healthy soil supports both agriculture and forestry. The mineral- and nutrient-rich portion of soil is called topsoil. Good topsoil absorbs and retains moisture yet allows water to drain. It is rich in organic matter and nutrients, but low in salts. Good topsoil is produced by long-term interactions between soil and the plants growing in it.

Topsoil can be a renewable resource if it is managed properly, but it can be damaged or lost if it is mismanaged. Healthy soil can take centuries to form but can be lost very quickly. And the loss of fertile soil can have dire consequences. Years of poorly managed farming in addition to severe drought in the 1930s badly eroded the once-fertile soil of the Great Plains. Thousands upon thousands of people lost their jobs and homes. The area essentially turned to desert, or, as it came to be known, a “dust bowl,” as seen in Figure 6–5. What causes soil erosion, and how can we prevent it?

Figure 6–5. The Dust Bowl A ranch in Boise City, Idaho, is about to be hit by a cloud of dry soil on April 15, 1935.
**Soil Erosion** The dust bowl of the 1930s was caused, in part, by conversion of prairie land to cropland in ways that left soil vulnerable to erosion. Soil erosion is the removal of soil by water or wind. Soil erosion is often worse when land is plowed and left barren between plantings. When no roots are left to hold soil in place, it is easily washed away. And when soil is badly eroded, organic matter and minerals that make it fertile are often carried away with the soil.

In parts of the world with dry climates, a combination of farming, overgrazing, seasonal drought, and climate change can turn farmland into desert. This process is called desertification, and it is what happened to the Great Plains in the 1930s. Roughly 40 percent of Earth’s land is considered at risk for desertification. Figure 6–6 shows vulnerable areas in North and South America.

**Deforestation**, or loss of forests, can also have a negative effect on soil quality. Healthy forests not only provide wood, but also hold soil in place, protect the quality of fresh water supplies, absorb carbon dioxide, and help moderate local climate. Unfortunately, more than half of the world’s old-growth forests (forests that had never been cut) have already been lost to deforestation. In some temperate areas, such as the Eastern United States, forests can regrow after cutting. But it takes centuries for succession to produce mature, old-growth forests. In some places, such as in parts of the tropics, forests don’t grow back at all after logging. This is why old-growth forests are usually considered nonrenewable resources.

Deforestation can lead to severe erosion, especially on mountainsides. Grazing or plowing after deforestation can permanently change local soils and microclimates in ways that prevent the regrowth of trees. Tropical rain forests, for example, look lush and rich, so you might assume they would grow back after logging. Unfortunately, topsoil in these forests is generally thin, and organic matter decomposes rapidly under heat and humidity. When tropical rain forests are cleared for timber or for agriculture, their soil is typically useful for just a few years. After that the areas become wastelands, the harsh conditions there preventing regrowth.

**Quick Facts**

**THE DUST BOWL**

The dust bowl of the 1930s was one of the worst environmental disasters in U.S. history. Here are some quick facts about the dust bowl.

- The main causes were drought and poor farming practices as natural grasslands were converted for growing wheat in the early twentieth century.
- States primarily affected by the dust bowl were Texas, Oklahoma, Kansas, Colorado, and New Mexico.
- Visibility during huge dust storms was reduced to less than 1 mile (1.6 km).
- By the mid-1930s, over 1 million acres of farmland had lost all or most of their topsoil.

**In Your Notebook** Describe the relationship between agriculture and soil quality.

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**Teach**

**Use Visuals**

Have students examine the map in Figure 6–6. Call on a student to read aloud the definition of desertification, and then discuss why some regions are at risk and some are not.

**Ask** What factors put a region at risk for desertification? (a dry climate combined with farming, overgrazing, seasonal drought, or climate change)

**Ask** Why isn’t the eastern United States at risk for desertification? (That region of the United States doesn’t have a dry climate.)

**DIFFERENTIATED INSTRUCTION**

**Advanced Students** Have interested students research the causes and effects of deforestation in the Amazon region of South America. Ask students to find out whether deforestation in the Amazon has resulted in areas becoming wastelands, as described in their text.

**Mystery CLUE**

Have students review the introduction to the Chapter Mystery to find one reason why islanders cut down trees. (for use as logs on which to move the moai) Encourage them to think of other reasons why societies cut down trees. (to burn wood for cooking and heating, to use wood in building houses) Students can go online to Biology.com to gather their evidence.

**Answers**

**FIGURE 6–6** Answers will vary depending on students’ location. Areas in the eastern United States are not vulnerable to desertification. Many areas in the West have very high vulnerability.

**IN YOUR NOTEBOOK** Sample answer: Agriculture depends on healthy soil. Without nutrient-rich topsoil, crops cannot grow, and without crops or other plants, soil is more likely to erode.
Lead a Discussion

Hold up a gallon of bottled water and a glass of tap water. Ask students to compare the sources of the water. (Sample answer: Most tap water is produced at a local water plant or comes from a well; sources vary, but about one fourth of bottled water comes from municipal water supplies.) Then, ask what happens to the bottle after the water is consumed. (Sample answer: It’s usually thrown away; sometimes it’s recycled.) Finally, have students assess which water—bottled or tap—uses more of Earth’s resources and judge which is a wiser use of those resources.

DIFFERENTIATED INSTRUCTION

**ELL: Focus on ELL: Extend Language**

**BEGINNER AND INTERMEDIATE SPEAKERS**

Have students make a *Word Wall* to help them learn lesson vocabulary terms, as well as any other difficult terms they encounter. On the word wall, students should divide terms into word parts, collaborate on writing a definition, make a pronunciation guide for each term, and, if possible, write translations for each term. Students can also add drawings to help them remember each term’s meaning.

*Study Wkbks A/B, Appendix S17, Word Wall.*

**LPR: Less Proficient Readers**

Display a map of the United States, and show students the extent of the Ogallala aquifer, from South Dakota to northern Texas. Explain that an aquifer is an underground supply of water that can be tapped for wells and used as a source of agricultural irrigation. Ask why this water is not an example of a renewable resource. (It would take too long to replenish if all the water were pumped out.)

**Biography In-Depth**

**OGALLALA AQUIFER**

The Ogallala aquifer underlies parts of eight states, including South Dakota, Wyoming, Nebraska, Kansas, Colorado, New Mexico, Oklahoma, and Texas. The Ogallala is the main source of water throughout the area for irrigation, as well as home and industrial water needs. Most of the discharge from the aquifer is for agricultural irrigation, and farmers began withdrawing the water in the 1930s. The aquifer is recharged—that is, water is added—mainly by precipitation. Because of the high withdrawal rate and the low rate of recharge, the water level has declined as much as 100 feet in some areas since the 1940s. State and local governments have developed plans to promote water conservation, including more efficient irrigation practices.
Pollutants may enter both surface water and underground water supplies that we access with wells. Once contaminants are present, they can be extremely difficult to get rid of. The primary sources of water pollution are industrial and agricultural chemicals, residential sewage, and nonpoint sources.

**Industrial and Agricultural Chemicals** One industrial pollutant is a class of organic chemicals called PCBs that were widely used in industry until the 1970s. After several large-scale contamination events, PCBs were banned. However, because PCBs often enter mud and sand beneath bodies of water, they can be difficult, if not impossible, to eliminate. Parts of the Great Lakes and some coastal areas, for example, are still polluted with PCBs. Other harmful industrial pollutants are heavy metals like cadmium, lead, mercury, and zinc.

Large-scale monoculture has increased the use of pesticides and insecticides. These chemicals can enter the water supply in the form of runoff after heavy rains, or they can seep directly into groundwater. Pesticides can be very dangerous pollutants. DDT, which is both cheap and long lasting, effectively controls agricultural pests and disease-carrying mosquitoes. But when DDT gets into a water supply, it has disastrous effects on the organisms that directly and indirectly rely on that water—a function of a phenomenon called biological magnification.

**Biological magnification** occurs if a pollutant, such as DDT, mercury, or a PCB, is picked up by an organism and is not broken down or eliminated from its body. Instead, the pollutant collects in body tissues. Primary producers pick up a pollutant from the environment. Herbivores that eat those producers concentrate and store the compound. Pollutant concentrations in herbivores may be more than ten times the levels in producers. When carnivores eat the herbivores, the compound is still further concentrated. Thus, pollutant concentration increases at higher trophic levels. In the highest trophic levels, pollutant concentrations may reach 10 million times their original concentration in the environment, as shown in Figure 6–8.

These high concentrations can cause serious problems for wildlife and humans. Widespread DDT use in the 1950s threatened fish-eating birds like pelicans, osprey, falcons, and bald eagles. It caused females to lay eggs with thin, fragile shells, reducing hatching rates and causing a drop in bird populations. Since DDT was banned in the 1970s, bird populations have recovered. Still a concern is mercury, which accumulates in the bodies of certain marine fish such as tuna and swordfish.

**In Your Notebook** In your own words, explain the process of biological magnification.

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**Uses of DDT**

The pesticide DDT (dichloro-diphenyl-trichloroethane) was discovered in the 1940s, and was first used during World War II to control body lice. In the 1950s, DDT was used extensively to combat diseases spread by insects and for insect control in general. In the United States, the use of DDT declined after the publication of Silent Spring by Rachel Carson in 1962. The book widely publicized the harmful effects of the pesticide. Since the 1970s, the use of DDT has been banned in many countries, including the United States and Canada. Because of its success in controlling disease-carrying insects, though, DDT has continued to be used in other parts of the world. In 2006, the World Health Organization (WHO) approved its use in Africa to fight malaria-carrying mosquitoes.

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**Use Visuals**

Begin a discussion of Figure 6–8 by pointing out that the figure represents a food chain, which students learned about in Chapter 3. Point out that the pyramid shows the concentration of DDT as orange dots in each trophic level. After students have examined the figure, ask them to fill in the blanks of this statement using the words decreases or increases.

- In a food chain, the concentration of a pollutant **increases** as the number of organisms at a trophic level **decreases**.

**Differentiated Instruction**

**L1: Struggling Students** Explain that the figure shows relative numbers, not absolute numbers. In other words, the figure is a model for how the concentration of the pollutant is magnified from one trophic level to the next higher level.

**Ask** If the level of a pollutant were 2 parts per million at the first trophic level, what would its concentration be at the second trophic level? (20 parts per million, or 2 × 10)

**Biology.com** Students can watch an animation of biological magnification by accessing Art in Motion: Biological Magnification.

**Address Misconceptions**

**Pollutants in a Food Chain** Some students may believe that pollutants such as DDT undergo no changes as they move through a food chain. Explain that chemicals may affect different kinds of animals differently, and chemicals may change in form as they move through a food chain. Point out that DDT was once widely used in the United States because it was effective in killing insects, mainly by affecting insect nervous systems. In fish-eating birds, though, the chemical affects the formation of eggshells, which was not foreseen by those who spread the chemical.

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**Answers**

**Figure 6–8** 10

**In Your Notebook** Sample answer: Biological magnification is the process by which a pollutant becomes more concentrated in the bodies of organisms at higher trophic levels.
Residential Sewage

Have you ever stopped to think what happens after you flush your toilet? Those wastes don’t disappear! They become residential sewage. Sewage isn’t poisonous, but it does contain lots of nitrogen and phosphorus. Reasonable amounts of these nutrients can be processed by and absorbed into healthy ecosystems. But large amounts of sewage can stimulate blooms of bacteria and algae that rob water of oxygen. Oxygen-poor areas called “dead zones” can appear in both fresh and salt water. Raw sewage also contains microorganisms that can spread disease.

Water Quality and Sustainability

One key to sustainable water use is to protect the natural systems involved in the water cycle. For example, as water flows slowly through a wetland, densely growing plants absorb some excess nutrients and filter out certain pollutants. Similarly, forests and other vegetation help purify water that seeps into the ground or runs off into rivers and lakes. Protecting these ecosystems is a critical part of watershed conservation. A watershed includes all the land whose groundwater, streams, and rivers drain into the same place—such as a large lake or river. The idea behind watershed conservation is simple: Cleaning up the pollution in a local area can’t do much good if the water running into it is polluted. You must consider the entire watershed to achieve long-lasting results.

Pollution control can have direct and positive effects on the water quality in a watershed. Sewage treatment can lower levels of sewage-associated bacteria and help prevent dead zones in bodies of water receiving the runoff. In some situations, agriculture can use integrated pest management (IPM) instead of pesticides. IPM techniques include biological control—using predators and parasites to regulate pest insects—the use of less-poisonous sprays, and crop rotation.

Conserving water is, of course, also important. One example of water conservation in agriculture is drip irrigation, shown in Figure 6–9, which delivers water drop by drop directly to the roots of plants that need it.

BUILD Vocabulary

RELATED WORD FORMS The verb purify is related to the noun pure.

To purify means “to make pure or clean.” Wetlands purify water by removing pollutants.

FIGURE 6–9 Drip Irrigation These cabbages are supplied water directly to their roots through drip irrigation. Tiny holes in water hoses (inset) allow farmers to deliver water only where it’s needed.

Biology In-Depth

TURNING WASTE INTO ENERGY

Some companies have been developing technology that turns waste matter and industrial pollution into energy resources. For example, with the support of the U.S. Environmental Protection Agency (EPA), a Georgia company has developed a process that converts municipal sewage and other organic wastes into a high-energy liquid fuel. This fuel burns more cleanly than coal. In addition to the production of a new energy source, this process eliminates problems associated with waste disposal, including odor, the release of air pollutants, and the use of land for landfills.
Atmospheric Resources

What are the major forms of air pollution?

The atmosphere is a common resource whose quality has direct effects on health. After all, the atmosphere provides the oxygen we breathe! In addition, ozone, a form of oxygen that is found naturally in the upper atmosphere, absorbs harmful ultraviolet radiation from sunlight before it reaches Earth's surface. It is the ozone layer that protects our skin from damage that can cause cancer.

The atmosphere provides many other services. For example, the atmosphere’s greenhouse gases, including carbon dioxide, methane, and water vapor, regulate global temperature. As you’ve learned, without the greenhouse effect, Earth’s average temperature would be about 30° Celsius cooler than it is today.

The atmosphere is never “used up.” So, classifying it as a renewable or nonrenewable resource is not as important as understanding how human activities affect the quality of the atmosphere. For most of Earth’s history, the quality of the atmosphere has been naturally maintained by biogeochemical cycles. However, if we disrupt those cycles, or if we overload the atmosphere with pollutants, the effects on its quality can last a very long time.

Air Pollution

What happens when the quality of Earth’s atmosphere is reduced? For one thing, respiratory illnesses such as asthma are made worse and skin diseases tend to increase. Globally, climate patterns may be affected. What causes poor air quality? Industrial processes and the burning of fossil fuels can release pollutants of several kinds. Common forms of air pollution include smog, acid rain, greenhouse gases, and particulates.

Smog

If you live in a large city, you’ve probably seen smog, a gray-brown haze formed by chemical reactions among pollutants released into the air by industrial processes and automobile exhaust. Ozone is one product of these reactions. While ozone high up in the atmosphere helps protect life on Earth from ultraviolet radiation, at ground level, ozone and other pollutants threaten the health of people, especially those with respiratory conditions. Many athletes participating in the 2008 Summer Olympics in Beijing, China, expressed concern over how the intense smog, seen in Figure 6–10, would affect their performance and health.

Apply Concepts

FIGURE 6–10 Smog Despite closing factories and restricting vehicle access to the city, Beijing remained under a blanket of dense smog just days before the 2008 Summer Olympics.

Answers

FIGURE 6–10 ozone

IN YOUR NOTEBOOK Sample answer: Both the atmosphere and fresh water are needed for healthy ecosystems, and both can be contaminated with pollutants. Fresh water is usually considered a renewable resource, though some sources of fresh water are not renewable. Fresh water may be possible to treat if it’s polluted. The atmosphere is never used up, and so it is neither renewable nor nonrenewable—but to protect the atmosphere, we need to prevent pollutants from being released in the first place.

Build Reading Skills

Explain that making an outline can help students understand the material and put it in a useful form for review. Have each student outline the subsection Air Pollution. Begin the outline on the board by writing the title Air Pollution. Tell students the primary heads of the outline should be the four common forms of air pollution described: Smog, Acid Rain, Greenhouse Gases, and Particulates. Under each primary head, they should add details about that form of air pollution. After they have finished their outlines, divide the class into small groups to compare outlines. Ask students to revise their outlines as they talk with other group members about the details they included.

DIFFERENTIATED INSTRUCTION

ELL English Language Learners Point out to English language learners that the term smog may remind them of another English word, fog. Explain that the two words are related. The origins of smog come from a description of this form of pollution in the early twentieth century, when gray-brown haze was described as a “smoky fog.” Parts of the two words were put together to make the word smog.
Use Visuals

Have students examine the effects of acid rain in Figure 6–11.

Ask What human activities produce the nitrogen and sulfur compounds that result in acid rain? (the burning of fossil fuels)

Point out that fossil fuels are burned in homes, in addition to factories.

Ask What do most Americans use in their homes that ultimately is derived from the burning of fossil fuels? (They use electricity, which is often produced in coal-fired or oil-fired power plants. Home heating is also usually generated by either oil or natural gas.)

Differentiated Instruction

L3 Advanced Students Have students collect samples of rainwater from various outdoor locations. Provide them with litmus paper for testing the pH of each sample. Have them also test tap water and compare the pH of the samples with the pH of tap water. Explain that all rainwater is slightly acidic (pH 6–7) because of carbon dioxide in the air. A pH of less than 5.5 qualifies as acid rain. Have students report their findings to the class.

Answers

In Your Notebook Flowcharts may vary, but should include this basic information: (1) Burning fossil fuels releases nitrogen and sulfur compounds. (2) The compounds combine with water vapor in the air and form nitric and sulfuric acids. (3) The acids can drift for many kilometers before falling as acid rain.

Purpose Students will interpret data about air pollution trends in the United States and infer what contributed to those trends.

Planning Review with students how the burning of fossil fuels contributes to air pollution. Point out that the graph shows percent change, not absolute values. Make sure students understand what an absolute value for each of the three variables (vehicle miles traveled, energy consumption, and aggregate emissions) might be.

Answers

1. Sample answer: The overall trend is a decrease in emissions. This is unexpected, because the trend for vehicle miles traveled has risen sharply during the same period. The trend for energy consumption has also risen, though not as sharply.

2. Sample answer: That graph would not start at zero for emissions. Rather, the label on the vertical axis would be a measure of emissions, such as parts per million, and the graph would start with the absolute value for emissions in 1980.

3. Sample answer: The trend in emissions is likely the result of improvements in technology such as more-efficient vehicle engines and less-polluting gasoline and other fuels. Part of the EPA’s job is to develop environmental regulations such as gas mileage mandates. These data show that, at least in part, these regulations have been working.
Air Quality and Sustainability  Improving air quality is difficult. Air doesn’t stay in one place and doesn’t “belong” to anyone. Automobile emission standards and clean-air regulations have improved air quality in some regions, however, and seem to be having a net positive effect, as shown in Figure 6–12. Efforts like these also have improved the atmosphere globally. At one time, for example, all gasoline was enriched with lead. But as leaded gasoline burned, lead was released in exhaust fumes and ultimately washed onto land and into rivers and streams. U.S. efforts to phase out leaded gasoline started in 1973 and were completed in 1996 when the sale of leaded gasoline was banned. Now that unleaded gasoline is used widely across the United States, lead levels in soils, rivers, and streams around the country have dropped significantly from earlier, higher levels.

Assessment Answers

1a. Sample answer: Soil erosion is caused when no roots are left to hold soil in place. When soil is badly eroded, organic matter and minerals that make it fertile are often carried away with the soil.

2b. Sample answer: Leaving stems and roots of the previous year’s crop in the soil between plantings can help hold soil in place. Crop rotation can help prevent soil erosion. The practice of contour plowing can limit erosion.

2a. Sample answer: The water cycle naturally renews Earth’s fresh water. In some places, though, freshwater supplies are limited.

3a. the oxygen we breathe, the ozone layer that absorbs harmful ultraviolet radiation, and the greenhouse gases that regulate global temperature

3b. The burning of fossil fuels releases pollutants of several kinds, including greenhouse gases, particulates, and the pollutants that produce smog and acid rain.

4. Producers, 0.004 ppm; small fish, 0.4 ppm; larger fish, 4 ppm; fish-eating birds, 40 ppm
Ecosystem diversity is also greater in a tropical area than in a desert. Species diversity in a tropical area is much greater than in a desert. 

**Answers**

**FIGURE 6–13** Sample answer: There is much greater species diversity in a tropical area than in a desert. Ecosystem diversity is also greater in a tropical area.

**Vocabulary**
- biodiversity
- ecosystem diversity
- species diversity
- genetic diversity
- habitat fragmentation
- ecological hot spot

**Taking Notes**

Preview Visuals Before you read, look at Figure 6–20. Record three questions you have about the map. When you’ve finished reading, answer the questions.

**Figures**

- Figure 6–13: A New Species
  - This tiny snake, native to the island of Barbados, is one of many recently discovered species. Photos of the snake were released in 2008. Infer: Why are you more likely to discover a new vertebrate species in a tropical area than in a desert?

**The Value of Biodiversity**

- **Why is biodiversity important?**
  - Biological diversity, or biodiversity, is the total of all the genetically based variation in all organisms in the biosphere. To biologists, biodiversity is precious, worth preserving for its own sake. But what kinds of biodiversity exist, and what value do they offer society?

- **Types of Biodiversity**
  - Biodiversity exists on three levels: ecosystem diversity, species diversity, and genetic diversity. Ecosystem diversity refers to the variety of habitats, communities, and ecological processes in the biosphere. The number of different species in the biosphere, or in a particular area, is called species diversity. To date, biologists have identified and named more than 1.8 million species, and they estimate that at least 30 million more are yet to be discovered. Much of this diversity exists among single-celled organisms. But new species of vertebrates, like the snake in Figure 6–13, are still being found.
  - Genetic diversity can refer to the sum total of all different forms of genetic information carried by a particular species, or by all organisms on Earth. Within each species, genetic diversity refers to the total of all different forms of genes present in that species. In many ways, genetic diversity is the most basic kind of biodiversity. It is also the hardest kind to see and appreciate. Yet, genetic diversity is vitally important to the survival and evolution of species in a changing world.
Valuing Biodiversity  You can’t touch, smell, or eat biodiversity, so many people don’t think of it as a natural resource. But biodiversity is one of Earth’s greatest natural resources. Biodiversity’s benefits to society include contributions to medicine and agriculture, and the provision of ecosystem goods and services. When biodiversity is lost, significant value to the biosphere and to humanity may be lost along with it.

- **Biodiversity and Medicine**  Wild species are the original source of many medicines, including painkillers like aspirin and antibiotics like penicillin. The chemicals in wild species are used to treat diseases like depression and cancer. For example, the foxglove, shown in Figure 6–14, contains compounds called digitalins that are used to treat heart disease. These plant compounds are assembled according to instructions coded in genes. So the genetic information carried by diverse species is like a “natural library” from which we have a great deal to learn.

- **Biodiversity and Agriculture**  Genetic diversity is also important in agriculture. Most crop plants have wild relatives, like the potatoes in Figure 6–15. These wild plants may carry genes we can use—through plant breeding or genetic engineering—to transfer disease or pest resistance, or other useful traits, to crop plants.

- **Biodiversity and Ecosystem Services**  The number and variety of species in an ecosystem can influence that ecosystem’s stability, productivity, and value to humans. Sometimes the presence or absence of a single keystone species, like the sea otter in Figure 6–16, can completely change the nature of life in an ecosystem. Also, healthy and diverse ecosystems play a vital role in maintaining soil, water, and air quality.

**FIGURE 6–14 Medicinal Plants**  Digoxin, a drug derived from digitalin compounds in the foxglove plant, is used to treat heart disease.

**FIGURE 6–15 Potato Diversity**  The genetic diversity of wild potatoes in South America can be seen in the colorful varieties shown here. The International Potato Center, based in Peru, houses a “library” of more than 4500 tuber varieties.

**FIGURE 6–16 Keystone Species**  The sea otter is a keystone species. When the otter population falls, the population of its favorite prey, sea urchins, goes up. Population increases in sea urchins, in turn, cause a dramatic decrease in the population of sea kelp, the sea urchin’s favorite food.

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**Biology In-Depth**

**A KEYSTONE SPECIES**

When a keystone species is removed from an ecosystem, dramatic changes usually follow. The sea otter is an example of a keystone species in the intertidal zone. This mammal once was native to much of the Pacific Coast of the North America. Hunting sea otters for fur caused their decline in the nineteenth century. Now, sea otter populations have been restored in some areas, such as California and southeastern Alaska. Where sea otters have returned, the population of sea urchins has declined, because otters hunt sea urchins. Kelp forests have grown, because sea urchins eat kelp. And, the population of bald eagles has increased, because bald eagles eat fish that thrive in kelp forests.

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**Teach**

**Lead a Discussion**

As a class, discuss the value of biodiversity, including the types of biodiversity and biodiversity’s benefits to society. Make sure students understand that biodiversity exists on three levels: ecosystem diversity, species diversity, and genetic diversity.

**Ask**  If an ecologist were to describe the number and variety of habitats in a biome, what level of biodiversity would he or she be referring to? (ecosystem diversity)

**Ask**  What could happen that would cause farmers to turn to a wild relative of a crop plant? (Sample answer: A devastating disease could spread through a crop. If a wild relative were resistant to the disease, then farmers could turn to those plants to replace or modify the crop plants.)

**DIFFERENTIATED INSTRUCTION**

**ELL**  English Language Learners  Tell students that the term biodiversity is a shortened form of biological diversity. Explain that diversity means “a variety.”

Talking about biodiversity, then, is a way of talking about the variety of organisms in an ecosystem or in the biosphere. Point out that they may have heard the term diversity used in describing the population of the United States, which includes a diversity of races and ethnic groups.

**LPR**  Less Proficient Readers  Have students make bulleted lists under the headings Biodiversity and Medicine, Biodiversity and Agriculture, and Biodiversity and Ecosystem Services. Each list should include details and examples about benefits of biodiversity to society.

**Biology.com**  Students compare data from two sites and learn to quantify biodiversity in the activity Data Analysis: Measuring Biodiversity.
Connect to the Real World

After students have read about habitat fragmentation, call on volunteers to name parks or other natural areas in their community. Make a list of these natural areas on the board. Then, have students estimate the size of each area on the list (or look up the areas ahead of time). Add the square areas of all the parks together, and circle the sum.

Ask What difference would it make to the area’s biodiversity if there were one natural area equal in size to the sum of all the existing natural areas? (Sample answer: There would be greater biodiversity in the one big area, with more genetic diversity and likely more species diversity.)

DIFFERENTIATED INSTRUCTION

Struggling Students To help students understand habitat fragmentation, have them think of a busy highway with forests on either side. What happens to animals when they try to cross the road to the other part of the forest—habitat that was once part of their geographic range? Often, they are injured or killed; this is a consequence of habitat fragmentation.

Discuss with students why a lack of biodiversity can make organisms more vulnerable to extinction and less able to survive disturbances caused by human activities. Students can go online to Biology.com to gather their evidence.

Struggling Students Have students use Art Review: Threats to Biodiversity to drag and drop labels onto a photo showing a region that has been developed by humans.

Quick Facts

MAMMAL EXTINCTIONS

In 2008, the International Union for Conservation of Nature (IUCN) released the results of a study of mammals and extinction. The study involved more than 1700 scientists in 130 countries. The findings included these:

- Of the 5487 species of mammals they counted in the world, at least 1141, or about 21 percent, face extinction.
- The organization listed 188 mammal species as critically endangered and another 29 mammal species as possibly already extinct.
- In the last 500 years, 76 mammal species have become extinct.
- The loss or degradation of habitat is affecting 40 percent of the world’s mammal species.
Hunting and the Demand for Wildlife Products  Humans can push species to extinction by hunting. In the 1800s, hunting wiped out the Carolina parakeet and the passenger pigeon. Today endangered species in the United States are protected from hunting, but hunting still threatens rare animals in Africa, South America, and Southeast Asia. Some animals, like many birds, are hunted for meat. Others are hunted for their commercially valuable hides or skins or because people believe their body parts have medicinal properties. Still others, like the parrots in Figure 6–18, are hunted to be sold as pets. Hunted species are affected even more than other species by habitat fragmentation because fragmentation increases access for hunters and limits available hiding spaces for prey. The Convention on International Trade in Endangered Species (CITES) bans international trade in products from a list of endangered species. Unfortunately, it’s difficult to enforce laws in remote wilderness areas.

Introduced Species  Recall that organisms introduced to new habitats can become invasive and threaten biodiversity. For example, more than 130 introduced species live in the Great Lakes, where they have been changing aquatic ecosystems and driving native species close to extinction. One European weed, leafy spurge, infests millions of hectares across the Northern Great Plains. On rangelands, leafy spurge displaces grasses and other food plants, and its milky latex can sicken or kill cattle and horses. Each year, ranchers and farmers suffer losses of more than $120 million because of this single pest.

Pollution  Many of the pollutants described in the last lesson also threaten biodiversity. DDT, for example, prevents birds from laying healthy eggs. In the United States, brown pelican, peregrine falcon, and other bird populations plummeted with widespread use of the chemical. Acid rain places stress on land and water organisms. Increased carbon dioxide in the atmosphere is dissolving in oceans, making them more acidic, which threatens biodiversity on coral reefs and in other marine ecosystems.

**In Your Notebook**  Why is acidic water harmful to coral?

**Answers**

**FIGURE 6–18**  Sample answer: There are fewer individuals of the species left to reproduce, and therefore hunting decreases the genetic diversity of the species and lessens its chances of surviving ecological disturbances.

**IN YOUR NOTEBOOK**  Sample answer: Corals, most of which have a “skeleton” of calcium carbonate, have evolved to thrive at a certain water pH. Acid rain makes the water more acidic, which can dissolve coral.

Quick Facts

**CITES**

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is an agreement between governments to make sure trade in wild animals and plants does not threaten their survival. The agreement came into force in 1975. By 2008, there were 173 countries that had joined in the agreement, including the United States. At that time, about 5000 species of animals and 28,000 species of plants were protected against exploitation in international trade. CITES is a voluntary agreement among countries, and its rules do not take the place of each country’s laws, which vary around the world.
LESSON 6.3

Lead a Discussion
Talk about the two strategies for conserving biodiversity (protecting individual species and preserving habitats and ecosystems). Make sure students understand why both are important.

**Ask** How does a national park such as Yellowstone National Park help in conserving biodiversity? (It conserves biodiversity by preserving habitats and ecosystems.)

**Ask** Why do you think human interests must be taken into account in conservation efforts? (Sample answer: If human interests are taken into account, populations around the world are more likely to support conservation efforts.)

**DIFFERENTIATED INSTRUCTION**

**Less Proficient Readers** Before leading the discussion above, write the Key Concept statement for the section on the board, with important words deleted.

1. To conserve ________, we must protect individual ________, preserve habitats and ________, and make certain that human neighbors of ________ areas benefit from participating in ________ efforts.

Ask students to fill in the blanks, using these words: biodiversity, conservation, ecosystems, protected, species. (Correct order should be biodiversity, species, ecosystems, protected, conservation.)

**Advanced Students** Have interested students find out whether the local zoo or aquarium is a member of the Association of Zoos and Aquariums. Ask students to inquire specifically about whether the zoo or aquarium participates in the Species Survival Plan Program. Have students report to the class on what they learned.

**Answers**

**FIGURE 6–19** Sample answer: Captive breeding increases a population’s genetic diversity by mating only the most genetically dissimilar animals. Also, as the program succeeds, there will be more individuals contributing to the gene pool.

**Climate Change** Climate change (a topic in the next lesson) is a major threat to biodiversity. Remember that organisms are adapted to their environments and have specific tolerance ranges to temperature and other abiotic conditions. If conditions change beyond an organism’s tolerance, the organism must move to a more suitable location or face extinction. Species in fragmented habitats are particularly vulnerable to climate change because if conditions change they may not be able to move easily to a suitable habitat. Estimates vary regarding the effects of climate change on biodiversity. If global temperatures increase 1.5°C–2.5°C over late twentieth-century temperatures, 30 percent of species studied are likely to face increased risk of extinction. If the global temperature increase goes beyond 3.5°C, it is likely that 40–70 percent of species studied will face extinction.

**Conserving Biodiversity**

**How do we preserve biodiversity?**

What can we do to protect biodiversity? Should we focus on a particular organism like the scarlet macaw? Or should we try to save an entire ecosystem like the Amazon rain forest? We must do both. At the same time, conservation efforts must take human interests into account.

**To conserve biodiversity, we must protect individual species, preserve habitats and ecosystems, and make certain that human neighbors of protected areas benefit from participating in conservation efforts.**

**Protecting Individual Species** In the past, most conservation efforts focused on individual species, and some of this work continues today. The Association of Zoos and Aquariums (AZA), for example, oversees species survival plans (SSPs) designed to protect threatened and endangered species. A key part of those plans is a captive breeding program. Members of the AZA carefully select and manage mating pairs of animals to ensure maximum genetic diversity. The ultimate goal of an SSP is to reintroduce individuals to the wild. Research, public education, and breeding programs all contribute to that goal. More than 180 species, including the giant panda shown in Figure 6–19, are currently covered by SSPs.

**Preserving Habitats and Ecosystems** The main thrust of global conservation efforts today is to protect not just individual species but entire ecosystems. The goal is to preserve the natural interactions of many species at once. To that end, governments and conservation groups work to set aside land as parks and reserves. The United States has national parks, forests, and other protected areas. Marine sanctuaries are being created to protect coral reefs and marine mammals.

**Quick Facts**

**COSTA RICA’S BIOLOGICAL RESERVES**

The Central American nation of Costa Rica has become a world leader in the effort to protect biodiversity. In exchange for reduction in its international debt, the Costa Rican government established eight biological reserves—extensive regions that include one or more undisturbed areas surrounded by buffer zones that are used by people for economic gain. The buffer zones provide a steady, lasting supply of forest products, water, and hydroelectric power and also support sustainable agriculture and ecotourism. Destructive practices that are incompatible with long-term ecosystem stability are prohibited in these zones. Costa Rica expects its biological reserves system to maintain at least 80 percent of the country’s native species. In addition, its thriving ecotourism industry is a significant source of income for the country.
The challenge is protecting areas that are large enough and that contain the right resources to protect biodiversity. To make sure that conservation efforts are concentrated in the most important places, conservation biologists have identified ecological “hot spots,” shown in red in Figure 6–20. An ecological hot spot is a place where significant numbers of species and habitats are in immediate danger of extinction. By identifying these areas, ecologists hope that scientists and governments can better target their efforts to save as many species as possible.

**Considering Local Interests** Protecting biodiversity often demands that individuals change their habits or the way they earn their living. In these cases it is helpful to offer some reward or incentive to the people or communities involved. The United States government, for example, has offered tax credits to people who’ve installed solar panels or bought hybrid cars. Similarly, many communities in Africa, Central America, and Southeast Asia have set aside land for national parks and nature reserves, like the park shown in Figure 6–21, to attract tourist dollars. In some Australian communities, farmers were paid to plant trees along rivers and streams as part of wildlife corridors connecting forest fragments. Not only did the trees help improve local water quality; they also improved the health of the farmers’ cows, which were able to enjoy shade on hot days!

The use of carbon credits is one strategy aimed at encouraging industries to cut fossil fuels use. Companies are allowed to release a certain amount of carbon into the environment. Any unused carbon may be sold back at a set market value or traded to other companies. This strategy encourages industries to pay for lower-emission machinery and to adopt carbon-saving practices. In this way, pollution is capped or cut without adding a financial burden to the industry involved. This helps protect the economy while reducing biodiversity loss due to pollution. These examples show that conservation efforts work best when they are both shading habitats and ecosystems that are ecological hot spots.

Figure 6–20, Ecological Hot Spots Conservation International identifies biodiversity hot spots using two criteria. The area (1) must contain at least 1500 species of native vascular plants, and (2) it must have lost at least 70 percent of its original habitat. The 34 hot spots seen here cover just 2.3 percent of Earth’s land surface, but they contain over 50 percent of the world’s plant species and 42 percent of its terrestrial vertebrates.

Figure 6–21, Ecotourism A tourist gets an elephant-size kiss from one of the over 30 rescued elephants at Thailand’s Elephant Nature Park.

**Use Visuals**

Have students examine the map in Figure 6–20 and read the caption. Make sure they understand the purpose of identifying these areas.

**Ask** What does Conservation International hope will result from identifying these ecological hot spots around the world? (They hope scientists and countries will direct their efforts at conserving biodiversity in these areas.)

**Ask** Which ecological hot spot includes part of the continental United States? (California Floristic Province)

Explain that this ecological hot spot includes most of the California coast and some of inland California. Point out that one endangered species in this area is the California condor.

**Differentiated Instruction**

**ELL Struggling Students** Have pairs of students work through Figure 6–20. Suggest they start by identifying the world’s continents. Then, have them describe where hot spots are on the map. Have pairs read aloud the figure caption and then discuss it. Then, suggest they discuss the strategy of preserving habitats and ecosystems that are ecological hot spots.

**Focus on ELL: Build Background**

**ALL SPEAKERS** Help students build their understanding of lesson concepts by setting up a Gallery Walk on biodiversity. Write the lesson vocabulary terms on separate pieces of chart paper and post them around the room. Have small groups rotate from term to term. At each term, group members should write what they know about it, using a particular color of pen. When the next group rotates to the term, its members should add to the previous group’s comments or correct mistakes and misunderstandings, using a different-colored pen. When groups return to the term they addressed first, have members summarize information about that term for the class.

**Study Wkbks A/B**, Appendix S6, Gallery Walk.
Lesson 6.3

**LESSON 6.3**

**Purpose** Students will analyze data about the recovery and reintroduction of golden lion tamarins.

**Planning** Review with students how species survival plans are designed to protect threatened and endangered species.

**Answers**
1. 545 percent
2. 400
3. They must be the offspring of the 153 GLTs that have been reintroduced from zoos since 1984.
4. Sample answer: Yes. Without the protection of zoos and aquariums, the animals might become extinct.

**Assess and Remediate**

**Evaluate Understanding**
Call on students to identify and describe the three types of biodiversity. Then, have students complete the 6.3 Assessment.

**Remediation Suggestion**
If students struggle to answer Question 2b, review with them the subsection, Altered Habitats.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

**Assessment Answers**

1a. Ecosystem diversity refers to the variety of habitats, communities, and ecological processes in the biosphere. Species diversity is the number of different species in the biosphere or in a particular area. Genetic diversity refers to the different forms of genetic information carried by individuals in a species or in the biosphere.

1b. Answers will vary. Students should mention specific benefits in medicine, agriculture, and ecosystem services.

2a. Altering habitats, hunting, introducing invasive species, releasing pollution into food webs, and climate change

2b. Sample answer: The smaller the habitat size, the less species diversity there is. The reason is that smaller size limits the number of species that can live in the space.

3a. To reintroduce genetically diverse individuals to the wild

3b. Sample answer: The strategy is a good one because it will conserve a high concentration of endangered species with one directed effort.

4. Sample answer: The hot spots mostly occur in areas classified as tropical rain forests or temperate woodland and shrubland. The correlation with tropical rain forests is not surprising, because this biome contains the greatest biodiversity. The correlation with temperate woodland and shrubland is somewhat surprising, though these areas also contain great biodiversity.


6.4 Meeting Ecological Challenges

THINK ABOUT IT Every year, the EPA awards up to ten President’s Environmental Youth Awards. Past winners have included an Eagle Scout from Massachusetts who encouraged people who fish to stop using lead weights that contaminate water and poison organisms, students from Washington State who reduced waste at their school and saved more than half a million dollars in the process, and a student from Florida who developed an outreach program to protect local sea turtles. What do these award winners have in common? They came up with ideas that protect the environment while satisfying both present and future needs. This kind of leadership is what will help us chart a new course for the future.

Ecological Footprints

How does the average ecological footprint in America compare to the world’s average? What is our impact on the biosphere today? To answer that question, think about the kind and amount of resources each of us uses. Ecologists refer to the human impact on the biosphere using a concept called the ecological footprint. The ecological footprint describes the total area of functioning land and water ecosystems needed both to provide the resources an individual or population uses and to absorb and make harmless the wastes that individual or population generates. Ecological footprints take into account the need to provide resources such as energy, food, water, and shelter, and to absorb such wastes as sewage and greenhouse gases. Ecologists use footprint calculations to estimate the biosphere’s carrying capacity for humans. An artist’s rendition of an ecological footprint is shown in Figure 6–22.

Footprint Limitations Ecologists talk about the ecological footprints of individuals, of countries, and of the world’s population. Calculating actual numbers for ecological footprints, however, is complicated. The concept is so new that there is no universally accepted way to calculate footprint size. What’s more, footprints give only a “snapshot” of the situation at a particular point in time.

Getting Started

Objectives
6.4.1 Explain the concept of ecological footprint.
6.4.2 Identify the role of ecology in a sustainable future.

Student Resources
Study Workbooks A and B, 6.4 Worksheets
Spanish Study Workbook, 6.4 Worksheets
Lab Manual B, 6.4 Hands-On Activity Worksheet

Teach for Understanding

ENDURING UNDERSTANDING The existence of life on Earth depends on interactions among organisms and between organisms and their environment.

GUIDING QUESTION How can we change our behaviors to help protect our planet?

EVIDENCE OF UNDERSTANDING After completing this lesson, give students the following assessment to show their understanding of an ecological challenge. Ask each student to write a summary of one of the case studies in this lesson. The summary should be two or three paragraphs long, and should describe the problem, identify the cause, and describe changes that could be made to address the problem. Call on volunteers to read their summaries to the class.

Unifying Concepts and Processes
I, II, III, IV

Content
C.4.a, C.4.c, C.4.e, C.5.e, C.6.b, F.2, F.3, F.4, F.5, F.6, G.1, G.2

Inquiry
A.2.a
Comparing Footprints Although calculating absolute footprints is difficult, ecological footprints can be useful for making comparisons among different populations, as shown in Figure 6–23. According to one data set, the average American has an ecological footprint over four times larger than the global average. The per person use of resources in America is almost twice that in England, more than twice that in Japan, and almost six times that in China. To determine the ecological footprint of an entire country, researchers calculate the footprint for a typical citizen and then multiply that by the size of the population.

In Your Notebook How have you contributed to your ecological footprint today? Give at least ten examples.

Ecology in Action How can ecology guide us toward a sustainable future? The future of the biosphere depends on our ecological footprints, global population growth, and technological development. Right now it’s more common to hear stories of ecological challenges than successes. Given the size of those challenges, you might be tempted to give up, to feel that things are getting worse, and that there is nothing we can do about it. But ecological research, properly collected, analyzed, and applied, can help us make decisions that will produce profoundly positive effects on the human condition. The basic principles of ecology can guide us toward a sustainable future. By (1) recognizing a problem in the environment, (2) researching that problem to determine its cause, and then (3) using scientific understanding to change our behavior, we can have a positive impact on the global environment. The following case studies illustrate the importance of the steps.

How Science Works

ECOLOGICAL FOOTPRINTS

Students may confuse the concept of ecological footprint with the concept of carbon footprint, which they have probably heard about. In general, a carbon footprint is a measure of human activities as they produce greenhouse gases and impact climate change. An ecological footprint is a larger and more complicated concept than a carbon footprint. In fact, an ecological footprint includes a version of the carbon footprint. The important idea to emphasize for students is that ecological and carbon footprints are valid concepts and good ways to compare environmental impacts of countries and cultures at a specific time.
Case Study #1: Atmospheric Ozone

Between 20 and 50 kilometers above Earth’s surface, the atmosphere contains a relatively high concentration of ozone called the ozone layer. Ozone at ground level is a pollutant, but the natural ozone layer absorbs harmful ultraviolet (UV) radiation from sunlight. Overexposure to UV radiation is the main cause of sunburn. It also can cause cancer, damage eyes, and lower resistance to disease. And intense UV radiation can damage plants and algae. By absorbing UV light, the ozone layer serves as a global sunscreen.

The following is an ecological success story. Over four decades, society has recognized a problem, identified its cause, and cooperated internationally to address a global issue.

1 Recognizing a Problem: “Hole” in the Ozone Layer

Beginning in the 1970s, satellite data revealed that the ozone concentration over Antarctica was dropping during the southern winter. An area of lower ozone concentration is commonly called an ozone hole. It isn’t really a “hole” in the atmosphere, of course, but an area where little ozone is present. For several years after the ozone hole was first discovered, it grew larger and lasted longer each year. Figure 6–24 shows the progression from 1981 to 1999. The darker blue color in the later image indicates that the ozone layer had thinned since 1981.

2 Researching the Cause: CFCs

In 1974 a research team led by Mario Molina, F. Sherwood Rowland, and Paul J. Crutzen demonstrated that gases called chlorofluorocarbons (CFCs) could damage the ozone layer. This research earned the team a Nobel Prize in 1995. CFCs were once widely used as propellants in aerosol cans; as coolant in refrigerators, freezers, and air conditioners; and in the production of plastic foams.

3 Changing Behavior: Regulation of CFCs

Once the research on CFCs was published and accepted by the scientific community, the rest was up to policymakers—and in this case, their response was tremendous. Following the recommendations of ozone researchers, 191 countries signed a major agreement, the Montreal Protocol, which banned most uses of CFCs. Because CFCs can remain in the atmosphere for a century, their effects on the ozone layer are still visible. But ozone-destroying halogens from CFCs have been steadily decreasing since about 1994, as shown in Figure 6–26, evidence that the CFC ban has had positive long-term effects. In fact, current data predict that although the ozone hole will continue to fluctuate in size from year to year, it should disappear for good around the middle of this century.

Check for Understanding

FOLLOW-UP PROBES

Ask Why is a “hole” in the ozone layer a problem, and what caused the “hole”? (The “hole” in the ozone layer is a problem because the ozone layer absorbs ultraviolet rays from the sun that can cause cancer and do other damage to life on Earth. The cause of the “hole” was the use of CFCs in aerosol cans, refrigerators, air conditioners, and plastic foams.)

ADJUST INSTRUCTION

If students have difficulty answering the question, have them reread the introduction to the case study and the paragraph (step 2) about the cause of the problem. Then, review the answer to the question in class discussion.

Connect to Chemistry

Explain that ozone is a form of pure oxygen, though different from the form we need for respiration. A molecule of oxygen has two atoms (O₂), while a molecule of ozone has three atoms (O₃). Further explain that CFCs degrade in the upper atmosphere, releasing fluorine and chlorine. Fluorine and chlorine are part of a group of elements called halogens. The halogens released by the CFCs combine with ozone molecules, destroying them. To emphasize how regulation of CFCs had a positive effect on the problem, focus students’ attention on the graph in Figure 6–26.

Ask What trend does the graph show between 1996 and 2007? (The atmospheric concentration of ozone-destroying halogens steadily decreased.)

DIFFERENTIATED INSTRUCTION

Struggling Students

To help students better understand what the ozone layer is, show them a labeled diagram of the layers of the atmosphere from an Earth science textbook. Point out that the ozone layer is part of the stratosphere, which is the layer just above the layer of the atmosphere next to Earth’s surface.

Less Proficient Readers

For struggling readers, take the time to preview the basic structure of how each case study is presented. Point out that step 1 explains how humans recognized there was a problem, step 2 details how scientists pinpoint what was or is causing the problem, and step 3 explains how humans are changing their behavior to help address it. Suggest students create a three-row table for each case study and fill it in with a summary sentence for each step.
Use Visuals

Focus students’ attention on the information in the graph in Figure 6–27 to discuss the case study of North Atlantic fisheries. Make sure students understand the meanings of biomass and catch. Explain that biomass refers to the total mass of cod in the North Atlantic, while catch refers to the total mass of the cod caught by the fishing boats.

Ask What caused the sharp increase in the catch between the late 1970s and the early 1980s? (Larger boats and high-tech fish-finding equipment made fishing more efficient, and the catch grew larger.)

Ask How do you know the decline in catch in the late 1980s was due to overfishing and not to something else, like a decline in fishing? (The biomass line shows that there was a sharp decline in the number of cod in the Atlantic during that time.)

Discuss the regulation of fisheries and why restoring fish populations has been slow.

DIFFERENTIATED INSTRUCTION

ELL English Language Learners Students may not understand the term overfishing. Explain that the prefix over- means “excessive” or “too much.” Overfishing, then, refers to too much fishing, which in this case resulted in fish being caught faster than they could replace themselves through reproduction. Point out that overfishing caused a once-renewable resource to become a nonrenewable resource.

Case Study #2: North Atlantic Fisheries

From 1950 to 1997, the annual world seafood catch grew from 19 million tons to more than 90 million tons. This growth led many to believe that the fish supply was an endless, renewable resource. However, recent dramatic declines in commercial fish populations have proved otherwise. This problem is one society is still working on.

1 Recognizing a Problem: More Work, Fewer Fish The cod catch has been rising and falling over the last century. Some of that fluctuation has been due to natural variations in ocean ecosystems. But often, low fish catches resulted when boats started taking too many fish. From the 1950s through the 1970s, larger boats and high-tech fish-finding equipment made the fishing effort both more intense and more efficient. Catches rose for a time but then began falling. The difference this time, was that fish catches continued to fall despite the most intense fishing effort in history. As shown in Figure 6–27, the total mass of cod caught has decreased significantly since the 1980s because of the sharp decrease of cod biomass in the ocean. You can’t catch what isn’t there.

2 Researching the Cause: Overfishing Fishery ecologists gathered data including age structure and growth rates. Analysis of these data showed that fish populations were shrinking. By the 1990s, cod and haddock populations had dropped so low that researchers feared these fish might disappear for good. It has become clear that recent declines in fish catches were the result of overfishing, as seen in Figure 6–28. Fish were being caught faster than they could be replaced by reproduction. In other words, the death rates of commercial fish populations were exceeding birth rates.

3 Changing Behavior: Regulation of Fisheries The U.S. National Marine Fisheries Service used its best data to create guidelines for commercial fishing. The guidelines specified how many fish of what size could be caught in U.S. waters. In 1996, the Sustainable Fisheries Act closed certain areas to fishing until stocks recover. Other areas are closed seasonally to allow fish to breed and spawn. These regulations are helping some fish populations recover, but not all. Aquaculture—the farming of aquatic animals—offers a good alternative to commercial fishing with limited environmental damage if properly managed.

Overall, however, progress in restoring fish populations has been slow. International cooperation on fisheries has not been as good as it was with ozone. Huge fleets from other countries continue to fish the ocean waters outside U.S. territorial waters. Some are reluctant to accept conservation efforts because regulations that protect fish populations for the future cause job and income losses today. Of course, if fish stocks disappear, the result will be even more devastating to the fishing industry than temporary fishing bans. The challenge is to come up with sustainable practices that ensure the long-term health of fishery with minimal short-term impact on the fishing industry. Exactly how to meet that challenge is still up for debate.

Quick Facts

GEORGES BANK

Georges Bank is located about 120 km off the coast of North America between Cape Cod and Nova Scotia. The Basques established a salted fish trade here around the year 1000. They retained control of the area until 1497 when John Cabot, who was searching for a northern spice route on behalf of King Henry VII of England, discovered it. Georges Bank owes its productivity to its position at the interception of two currents—the cold, nutrient-rich Labrador current and the warmer Gulf stream. Once among the most productive fisheries, the National Marine Fisheries Service reported in 1994 that cod stock on Georges Bank had declined 40 percent in just four years. They concluded that in order to be sustainable, fishing fleets would have to be cut in half.
Case Study #3: Climate Change

Global climate involves cycles of matter across the biosphere and everything modern humans do—from cutting and burning forests to manufacturing, driving cars, and generating electricity. The most reliable current information available on this subject comes from the 2007 report of the Intergovernmental Panel on Climate Change (IPCC). The IPCC is an international organization established in 1988 to provide the best possible scientific information on climate change. IPCC reports contain data and analyses that have been agreed upon and accepted by 2500 climate scientists from around the world and the governments participating in the study.

Recognizing a Problem: Global Warming

The IPCC report confirms earlier observations that global temperatures are rising. This increase in average temperature is called global warming. Remember that winds and ocean currents, which are driven by differences in temperature across the biosphere, shape climate. Given this link between temperature and climate, it isn’t surprising that the IPCC report discusses more than warming. The report also discusses climate change—changes in patterns of temperature, rainfall, and other physical environmental factors that can result from global warming. There are many lines of evidence, both physical and biological, that have contributed to our current understanding of the climate change issue.

- Physical Evidence

Physical evidence of global warming comes from several sources. The graphs in Figure 6–30, taken from data in the 2007 IPCC report, show that Earth’s temperatures are getting warmer, its sea ice is melting, and its sea levels are rising. Eleven of the twelve years between 1995 and 2006 were among the warmest years since temperature recording began in 1850. Between 1906 and 2005, Earth’s average global temperature rose 0.74°C. The largest changes are occurring in and near the Arctic Circle. Average temperatures in Alaska, for example, increased 2.4°C over the last 50 years. Sea level has risen since 1961 at a rate of 1.8 mm each year. This increase is caused by warmer water expanding and by melting glaciers, ice caps, and polar ice sheets. Satellite data confirm that arctic sea ice, glaciers, and snow cover are decreasing.

Use Visuals

Have students study the graphs in Figure 6–30. Make sure they understand the source of the data. Then, talk about the physical evidence of global warming.

Ask Between 1860 and 2002, did the land-surface air temperature change? (Sample answer: yes, but the fluctuations weren’t large enough to change the approximate average temperature)

Ask When did the downward trend in mean global sea ice begin? (In about the late 1960s)

Ask What has been the trend in global sea level since about 1920? (The trend since about 1920 is a rising sea level.)

Differentiated Instruction

ELL English Language Learners Explain to students new to English that global is the adjectival form of the word globe, which means a “sphere” or rounded ball. Explain that the term globe is often used as a synonym for Earth or the world. The adjective global, then, means “worldwide.”

LPR Less Proficient Readers Students may have difficulty distinguishing between the terms global warming and climate change, since the two terms are often used interchangeably in common speech. Ask a volunteer to read the definitions of the two terms aloud. Then, point out that the two have a cause-and-effect relationship.

Ask Which is the cause, and which is the effect? (Global warming is the cause; climate change is the effect.)

Quick Facts

THE IPCC

The World Meteorological Organization and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC does not conduct research on its own. Instead, its scientists assess scientific, technical, and economic data related to climate change. The information the organization provides in its reports is based on scientific evidence, and the IPCC makes no policy recommendations to governments.
**Teach continued**

**Lead a Discussion**

Talk about how much warming is expected to occur and what the consequences will be.

**Ask** What are the possible effects for towns and cities along the coasts of the United States? *(Because of the rise in sea level, some towns and cities may be flooded.)*

**Ask** Why is it possible that global warming will cause the Sahara Desert to become greener? *(Sample answer: Global warming will cause changes in weather patterns throughout the world. If weather patterns change in a certain way, the Sahara could receive more rain than is normal today.)*

Turn students' attention to what might occur in their local region as a result of global warming. Have them predict changes both for humans and for other organisms native to the region.

**DIFFERENTIATED INSTRUCTION**

**EL Advanced Students** Have interested students conduct research to answer this question: How can scientists know about the concentration of greenhouse gases over 2000 years ago? Students should find out about ice core analysis. Have them share what they learn with the class.

**Focus on ELL:**

**Access Content**

**BEGINNING AND INTERMEDIATE SPEAKERS**

Have pairs of students make a Cause and Effect Diagram for Case Study #3. Start the diagram for them by identifying climate change as the cause. Suggest they read the paragraphs on the biological and physical evidence associated with climate change to help them identify effects. Accept words or short phrases from beginning speakers. Suggest intermediate speakers write a simple sentence to identify each effect.

**Study Wkbks A/B,** Appendix S18, Cause and Effect Diagram. **Transparencies, GO1.**

**Address Misconceptions**

*Climate vs. Weather* Some students may doubt predictions about climate change because they have witnessed many wrong predictions about the weather. Explain that there is a big difference between weather and climate. Predicting atmospheric conditions in local areas is very difficult, but climate is much more predictable.

**Check for Understanding**

**HAND SIGNALS**

Give students the following questions, and ask them to show a thumbs-up sign if they can answer a question, a thumbs-down sign if they can't, or a waving-hand sign if they're not sure.

* What changes in patterns does climate change involve?
* What is strengthening the atmosphere's natural greenhouse effect?
* What changes in behavior need to occur to minimize further global warming?

**ADJUST INSTRUCTION**

For any question that received thumbs-down or waving-hand sign, have students write a one-sentence response to the question using the text as a resource.
3 Changing Behavior: The Challenges Ahead  You have seen how research has led to actions that are preserving the ozone layer and attempting to restore fisheries. In terms of global climate, great challenges lie ahead of us. Scientists have been saying for more than two decades that the world needs to recognize the importance of climate change and take steps to minimize further warming. The changes in behavior needed to cut back on greenhouse gas emissions will be major and will require input from economics and many other fields beyond biology. Some changes will rely on new technology for renewable energy and more efficient energy use. Because changing our use of fossil fuels and other behaviors will be difficult, researchers continue to gather data as they try to make more accurate models. In the meantime, we have begun to see the emergence of electric cars, recycled products, and green buildings.

Nations of the world have begun holding international climate summits, at which they attempt to work out agreements to protect the atmosphere and climate—both of which are truly global issues. As the world, and our own government, tries to work through these challenges, remember that the purpose of ecology is not to predict disaster or to prevent people from enjoying modern life. The world is our island of life. Hopefully, humanity can work toward a day when scientific information and human ingenuity help us reach the common goal of preserving the quality of life on Earth.

Assessment Answers

1a. An ecological footprint describes the total area of functioning land and water ecosystems needed both to provide the resources an individual or population uses and to absorb and make harmless the wastes that an individual or population generates.

1b. The limitations are that there is no universally accepted way to calculate footprint size and footprints give only a “snapshot” of the situation at a particular point in time. Ecologists can best use them to make comparisons among different populations.

2a. It absorbs harmful UV radiation from sunlight.

2b. Physical evidence: Data show that Earth’s temperatures are getting warmer, its sea ice is melting, and its sea levels are rising. Biological evidence: Data confirm that many species are responding as though they are experiencing rising temperatures.

2c. Sample answer: A solution would be to place strict, worldwide limits on catching all types of fishes for many years. This would help by giving fish populations time to increase to sustainable levels. The challenge in implementing such limits would be to persuade all countries to go along with the plan. Incentives for fishing companies would likely be needed.

3. Sample answer: The burning of fossil fuels is adding more carbon dioxide to the atmosphere and depleting it from fossil fuel reservoirs. Since carbon from the atmosphere can dissolve in water, it is also increasing the amount of carbon in bodies of water.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Acid Rain and Plants described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Make sure students wear goggles and a lab apron. Caution them to be careful in handling glassware and other breakable materials and to avoid getting the solutions on their skin. Have students wash their hands at the end of the lab.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 150.

NATIONAL SCIENCE EDUCATION STANDARDS

CONTENT F.4, F.5
INQUIRY A.1.b, A.1.c, A.2.d, C.4.e

Pre-Lab: Acid Rain and Seeds

Problem How does acid rain affect seed germination?
Materials white vinegar, distilled water, large test tubes, test-tube rack, glass-marking pencil, 25-mL graduated cylinder, food coloring, pipette, pH paper, dried beans, paper towels, zip-close plastic bags, stick-on labels, hand lens

Lab Manual Chapter 6 Lab
Skills Focus Design an Experiment, Organize Data, Measure, Graph

Connect to the Every organism alters its environment in some way. Elephants uproot trees, prairie dogs dig tunnels, and corals build reefs. But no other organism has as much impact on the global environment as humans. One of the ways that humans affect global ecology is by burning fossil fuels. The burning produces carbon dioxide, which can accumulate in the atmosphere and cause climate change. Other products react with water to form nitric and sulfuric acids. Rain that contains these acids can damage many things, including stone statues and growing plants. In this lab, you will investigate the effect of acid rain on seeds.

Background Question
a. Review What does a pH scale measure?
b. Review Which solution is more acidic, one with a pH of 4.0 or one with a pH of 5.0, and why?
c. Explain Use the water cycle to trace the path from acids in water vapor to plants.

Pre-Lab Questions
Preview the procedure in the lab manual.
1. Design an Experiment What do you think the purpose is of adding food coloring to the vinegar in Part A?
2. Infer How will you know that a seed has germinated?
3. Using Models In this lab, what do the solutions represent?

Pre-Lab Answers

BACKGROUND QUESTIONS
a. A pH scale measures the concentration of H\(^+\) ions in a solution.
b. The solution with a pH of 4.0 is more acidic because it has a greater concentration of H\(^+\) ions (ten times as many per unit volume).
c. Sample answer: Water vapor in the atmosphere can condense and fall to Earth’s surface as rain, which can contain dissolved acids. Some rain is absorbed into the soil where it can enter plants through their roots.

PRE-LAB QUESTIONS
1. Sample answer: As the vinegar is diluted with water, the intensity of the color will decrease. The food coloring provides a visual indicator for the decreased concentration of acid (H\(^+\) ions) in the solutions.
2. Sample answer: The seed coat will crack and a root will be visible.
3. Sample answer: The solutions represent rain with different concentrations of acids.
Humans affect natural ecological processes through agriculture, urban development, and industry. But ecological science gives us strategies for sustainable development, ways we can protect the environment without slowing human progress.

#### 6.1 A Changing Landscape

- Humans affect regional and global environments through agriculture, development, and industry in ways that have an impact on the quality of Earth's natural resources, including soil, water, and the atmosphere.
- Sustainable development provides for human needs while preserving the ecosystems that produce natural resources.

#### 6.2 Using Resources Wisely

- Healthy soil supports both agriculture and forestry.
- It is possible to minimize soil erosion through careful management of both agriculture and forestry.
- The primary sources of water pollution are industrial and agricultural chemicals, residential sewage, and nonpoint sources.
- Common forms of air pollution include smog, acid rain, greenhouse gases, and particulates.

#### 6.3 Biodiversity

- Biodiversity's benefits to society include contributions to medicine and agriculture, and the provision of ecosystem goods and services.
- Humans reduce biodiversity by altering habitats, hunting, introducing invasive species, releasing pollution into food webs, and contributing to climate change.
- To conserve biodiversity, we must protect individual species, preserve habitats and ecosystems, and make certain that human neighbors of protected areas benefit from participating in conservation efforts.

<table>
<thead>
<tr>
<th>biodiversity</th>
<th>ecosystem diversity</th>
<th>genetic diversity</th>
<th>species diversity</th>
<th>habitat fragmentation</th>
<th>ecological hot spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>166</td>
<td>166</td>
<td>166</td>
<td>166</td>
<td>168</td>
<td>171</td>
</tr>
</tbody>
</table>

#### 6.4 Meeting Ecological Challenges

- According to one data set, the average American has an ecological footprint over four times larger than the global average.
- By (1) recognizing a problem in the environment, (2) researching that problem to determine its cause, and then (3) using scientific understanding to change our behavior we can have a positive impact on the global environment.

<table>
<thead>
<tr>
<th>ecological footprint</th>
<th>aquaculture</th>
<th>global warming</th>
</tr>
</thead>
<tbody>
<tr>
<td>173</td>
<td>176</td>
<td>177</td>
</tr>
</tbody>
</table>

#### Performance Tasks

**SUMMATIVE TASK** Have students work in small groups to create a pamphlet that could be distributed throughout the community to teach people about the impact humans have on the environment. Tell groups they should include information on sustainable development; using soil, water, and atmospheric resources wisely; the importance of biodiversity; and the challenges humans face in the future. Pamphlets should be a combination of text and illustrations.

**TRANSFER TASK** Have each student write a magazine article describing a success story of an environmental activist who persuaded a community to change a development plan in order to conserve biodiversity or use resources wisely. Explain to students that, although the situation is hypothetical, their description of humans' impact on the environment should reflect what they have learned in the chapter.

**Answers**

**THINK VISUALLY**

Sample answer: (1) Primary producers in an aquatic food web pick up DDT in the water. (2) Zooplankton consume primary producers, and the concentration of DDT is magnified by 10. (3) Small fish consume zooplankton, and the concentration of DDT is magnified by 10. (4) Large fish consume small fish, and the concentration of DDT is magnified by 10. (5) Fish-eating birds consume large fish, and the concentration of DDT is magnified by 10. (6) The concentration of DDT in the fish-eating birds is high enough to cause females to produce thin, fragile eggshells. (7) The hatching rate falls, and the population of the birds decreases.
Lesson 6.1

UNDERSTAND KEY CONCEPTS
1. c 2. c
3. They cut trees to plant crops and introduced nonnative plants, pigs, chickens, dogs, and rats.
4. Sample answer: breathable air, drinkable water, fertile soil, fossil fuels

THINK CRITICALLY
5. Sample answer: Every possible material should be placed in recycle bins, including cans, bottles, plastics, and paper. Food wastes should be composted. Hazardous wastes should be collected and disposed of in safe ways.
6. Sample answer: Both renewable and nonrenewable resources are made by natural ecosystems. However, renewable resources can be produced or replaced by a healthy ecosystem while nonrenewable resources cannot be within a reasonable amount of time.
7. Sample answer: Because they are large and homogeneous, monocultures are more vulnerable to disease and pests because if a disease attacks one plant, it can quickly spread to all the other plants and destroy the entire monoculture.

Lesson 6.2

UNDERSTAND KEY CONCEPTS
8. c 9. b 10. b 11. a
12. In sustainable forestry, trees are replanted after they are cut, and no more are cut down than are needed or that can be replaced. In deforestation, trees are cut arbitrarily and are not replanted.
13. industrial and agricultural chemicals, residential sewage, and nonpoint sources such as grease and oil washed off streets by rain or the chemicals released into the air by factories and automobiles

THINK CRITICALLY
14. Sample answer: Covering soil with mulch or compost near the bases of plants could reduce soil erosion. A simple experiment to test this hypothesis would be to grow two areas of the same crop, using mulch or compost in one area and not in the other. Results would support the hypothesis if the area of crops with mulch or compost produced more than the area without.

Lesson 6.3

UNDERSTAND KEY CONCEPTS
17. b
18. a small area of habitat surrounded by a different habitat
19. ecosystem diversity, species diversity, genetic diversity
Lesson 6.4

UNDERSTAND KEY CONCEPTS

22. d  23. b

24. Earth’s temperatures are getting warmer, sea ice is melting, and sea levels are rising.

25. Sample answer: Organisms move toward cooler places away from the equator and from warm lowlands to cooler, higher altitudes. Plants flower and animals breed earlier as though spring begins earlier.

THINK CRITICALLY

20. Sample answer: The loss of biodiversity would limit the medicines that could be developed, make crop plants more vulnerable to diseases, and it would make ecosystems less stable, productive, and valuable.

21. Species diversity is the number of different species in the biosphere or in a particular area. Ecosystem diversity refers to the variety of habitats, communities, and ecological processes in the biosphere.

After students have read through the Chapter Mystery, discuss how the actions of the Rapa Nui resulted in the destruction of the forests on Easter Island.

Ask What activities of the Rapa Nui resulted in destruction of Easter Island’s forests? (They cleared trees for agriculture, cut trees to use the logs in moving the moai, and cut trees to make canoes.)

Ask How did the rats reach Easter Island? (They came as stowaways on the Rapa Nui’s boats.)

Ask How did an invasive species contribute to the deforestation of the island? (The rats destroyed coconuts that contained the trees’ seeds.)

CHAPTER MYSTERY ANSWERS

1. Sample answer: Because of the small size of the island, relatively few species lived there, and the populations of those species were relatively small. The lack of species diversity and genetic diversity made the organisms native to the island vulnerable to disturbance.

2. Sample answer: Easter Island is smaller, the climate is harsher, and the biological diversity is more limited than in the Hawaiian Islands. Those differences made the ecosystem on Easter Island much more vulnerable to the disturbances of human activities than were the ecosystems on the Hawaiian Islands.

3. Sample answer: The experiences of the Rapa Nui, especially, should be a lesson to global human society. The Rapa Nui both intentionally and unintentionally destroyed Easter Island’s forests, making life for humans impossible on the island. Global human society should learn from that example to use resources wisely and be aware of changes in the environment that could make human life on Earth difficult in the future.

Have students watch the video What Do Zoos . . . Do? in which the Untamed Science crew explores a zoo’s role in protecting biodiversity.
THINK CRITICALLY

26. The ozone layer hasn’t repaired itself fully yet because CFCs can remain in the atmosphere for a century. CFCs were widely used for many decades before the ban went into place, so their effects are still visible.

27. Sample answer: The steps taken include regulating how many fish could be caught in U.S. waters, closing certain areas to fishing until stocks recover, closing some areas seasonally to allow fishes to breed and spawn, and using aquaculture as an alternative to fishing. Overfishing is a complex issue because fleets from other countries fish outside of U.S. territorial waters, and countries are reluctant to accept conservation efforts that could cause job loss.

Connecting Concepts

USE SCIENCE GRAPHICS

28. Sample answer: The catch would decrease.

29. Sample answer: The fishing of bluefin tuna should be regulated, strictly limiting the catch for at least the next decade.

WRITE ABOUT SCIENCE

30. Sample answer: Wetlands naturally filter toxins and other materials from water, making the water resources safer for humans, as well as healthier for affected ecosystems. In addition, wetlands provide habitats for many species, increasing an area’s ecosystem diversity and species diversity.

31. Sample answer: Species diversity in an area contributes to the overall biodiversity of the area. Biodiversity’s benefits to society include contributions to medicine and agriculture and the provision of ecosystem goods and services.

32. Sample answer: Most coastal waters are in the photic zone. As a result, they receive plenty of solar energy for the producers that support the food chains there. In addition, runoff from rivers and streams may bring nutrients to coastal waters that also increase the productivity of these ecosystems. Finally, estuaries, the intertidal zone, and the coastal ocean provide varied habitats that encourage biodiversity.

33. Interpret Graphs Of domestic species and foreign species, which showed the greatest percentage increase between the 1901–1950 period and the 1951–1996 period?
   a. domestic species
   b. foreign species
   c. Both increased the same amount.
   d. There is not enough information to tell.

34. Draw Conclusions Which of the following statements about introduced species is most likely true based on the data shown?
   a. Species introduced from foreign countries are always more harmful than species relocated within the country.
   b. All introduced species are brought into this country by accident.
   c. It is likely that the increase in the number of introduced species is due to increased global travel, trade, and communication.
   d. The number of introduced species is likely to fall in the next half-century.

**ANSWERS**

33. b
34. c
Multiple Choice

1. Which of the following statements about renewable resources is TRUE?
   A. They are only found in tropical climates.
   B. They can never be depleted.
   C. They are replaceable by natural means.
   D. They regenerate very quickly.

2. Which of the following is a nonrenewable resource?
   A. wind
   B. fresh water
   C. coal
   D. topsoil

3. Which of the following is NOT a direct effect of deforestation?
   A. decreased productivity of the ecosystem
   B. soil erosion
   C. biological magnification
   D. habitat destruction

4. The total variety of organisms in the biosphere is called
   A. biodiversity.
   B. species diversity.
   C. ecosystem diversity.
   D. genetic diversity.

5. Ozone is made up of
   A. hydrogen.
   B. oxygen.
   C. nitrogen.
   D. chlorine.

6. Ozone depletion in the atmosphere has been caused by
   A. monoculture.
   B. CFCs.
   C. suburban sprawl.
   D. soil erosion.

7. In a food chain, concentrations of harmful substances increase in higher trophic levels in a process is known as
   A. biological magnification.
   B. genetic drift.
   C. biological succession.
   D. pesticide resistance.

8. Which of the following statements about fire ants in the United States is TRUE?
   A. They reproduce slowly.
   B. They are a native species of the United States.
   C. They are an invasive species.
   D. They do not compete with other ant species.

9. By 2010, fire ants are MOST likely to
   A. have spread to a larger area.
   B. have reached their carrying capacity.
   C. die out.
   D. return to South America.

Open-Response

10. Describe how ecologists use the ecological footprint concept.

Questions 8 and 9

Fire ants first arrived in the United States in 1918, probably on a ship traveling from South America to Alabama. The maps below show the geographic location of the U.S. fire ant population in 1953 and 2001.

Sample answer: They can use it to analyze human impact on ecosystems and make comparisons among different populations.

Test-Taking Tip

USE TIME WISELY

Advise students that if they are taking a long time to answer a question, they should move on to other questions and come back to the difficult question later. In answering other questions, they may remember the information needed to answer the skipped question.
Plan Ahead

Have students preview the Unit 2 Project a few days before the day of debate. Suggest they review ways in which human activities can affect the environment. Then, divide the class into groups of four. Assign each member of the groups one of the four roles for the debate. Tell students they might search online to find evidence to support the position assigned. Encourage students to talk to classmates with the same role about evidence and arguments that could be persuasive in a debate.

Materials  Internet access for research

Monitor the Project

Suggest students make lists of evidence and arguments supporting the position of the role they have taken. Ask individual students how they are preparing for the debate and what evidence they have found that supports their position. On debate day, each group could be given about 10 minutes to debate the issue, or students with the same role could collaborate in a debate that includes the entire class.

Project Assessment

Make sure students use the rubric and reflection questions to assess their work. Then, use the rubric to assign a final score. If desired, talk with students about any differences between their self-assessment scores and your assigned score.

Unit Project

Development Debate

A large company wants to build a new factory on your town’s wetlands. Many people in the town are opposed to the idea, claiming it will disturb the local ecosystem and cause problems for residents. Others support the development, arguing that the new factory will bring jobs and money into the town. Representatives have been called in to debate the issue before the town council.

Your Task  Take on one of the stakeholder roles listed below. Find evidence to support that point of view and debate the issue in class. The roles are:

• Conservation ecologist
• CEO of the company
• Town mayor who supports the development
• Resident of the town who lives next to the wetlands

Be sure to:
• justify your arguments with credible information,
• present your arguments in a clear and convincing manner.

Reflection Questions

1. Score your performance using the rubric below. What score did you give yourself?
2. What did you do well in this project?
3. What about your performance needs improvement?
4. After hearing various sides of the argument, meet with a partner and discuss which side you agree with the most. Justify your opinion.

Assessment Rubric

<table>
<thead>
<tr>
<th>Score</th>
<th>Evidence Provided</th>
<th>Quality of Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Student justifies his/her argument with sophisticated and highly credible information.</td>
<td>Ideas are presented in a highly convincing and clear manner. Student shows a deep understanding of the issues involved.</td>
</tr>
<tr>
<td>3</td>
<td>Student justifies his/her argument with logical and credible information.</td>
<td>Ideas are presented in an effective and clear manner.      Student shows a solid understanding of the issues involved.</td>
</tr>
<tr>
<td>2</td>
<td>Student provides some credible information, but other points are weak or inaccurate.</td>
<td>Some ideas are presented in an unclear manner.             Student shows a limited understanding of the issues involved.</td>
</tr>
<tr>
<td>1</td>
<td>Student provides mostly illogical and invalid evidence to support his/her argument.</td>
<td>Most ideas are presented in an unclear manner.             Student shows a very limited understanding of the issues involved.</td>
</tr>
</tbody>
</table>

21st Century Skills

To be successful in the 21st century, students need skills and learning experiences that extend beyond subject area mastery. The Unit 2 Project helps students build the following 21st Century Skills: Information and Media Literacy; Communication Skills; Critical Thinking and Systems Thinking; Problem Identification, Formulation, and Solution; Interpersonal and Collaborative Skills; Self-Direction; Accountability and Adaptability; and Social Responsibility.

FOCUS ON CREATIVITY AND INTELLECTUAL CURIOSITY  Extend this Unit Project by asking small groups of students to use what they have learned from the debate to write a screenplay about an environmental controversy within a community.

For more practice building 21st Century Skills, see The Chapter Mystery pages in Study Workbook A.
Dear Colleague,

I can still remember the first time I looked through a microscope and saw a living cell. It was in Paul Zong’s ninth-grade biology class in my hometown high school in New Jersey. After carefully instructing us in the proper use of the microscope, our teacher placed a drop of water on every student's slide and told us to have a look. I couldn't believe my eyes. Glistening creatures swam across the field of view. They twisted and turned, I thought, almost as if they were alive. I think I said that out loud, because I can remember Mr. Zong’s deep, gentle laugh and a pat on my shoulder. “They are alive, Kenny! They’re alive just like you and me.”

Later that year, I transformed a corner of the small room I shared with my brother into a miniature laboratory. A tiny desk lamp glowed day and night, providing energy for nearly a dozen test-tube colonies of Euglena. At the end of the year, those cells would become a science project, the very first research I would ever do on my own. What stuck with me from that first experience was the realization that the cell is life itself. Everything that we associate with life, from growth and reproduction to digestion and movement, happens at the level of the cell.

I won a ribbon that year for my study of light's effect on the growth of Euglena. Although I have long since misplaced the ribbon, I hope I never lose the greater gift that came from a year of study in that biology classroom—a sense of amazement that returns every time I sit down at a microscope in my laboratory.

I hope that you and your students will find some of that amazement written into the pages of this unit. As a cell biologist, I especially hope to give students an appreciation of the roles that cells play in every aspect of life. In these four chapters, we have done our best to explain how cells live and grow, how they transform energy, and how they pass information along from one generation to the next.
Connect to the Big Idea

Diatoms are single-celled organisms found in both fresh and salt water. Use the photograph of freshwater diatoms to help students understand that cells make up all living things, whether an organism consists of one cell, like a diatom, or many cells, as in a human or a corn plant. Emphasize that cells are dynamic. They are equipped with intricate parts, each of which has a specific function. Have students predict some of the challenges faced by cells. (Sample answers: They must take in and give off water and other raw materials, use energy, reproduce, and live in balance with their environment. At this point, accept all reasonable answers.) Explain that cells face the same challenges whether they are a single diatom in a human body, or in a plant. Tell students that, as they read this chapter, they should be guided by the Chapter 7 Essential Question, How are cell structures adapted to their functions?

Have students read over the Chapter Mystery. Ask what they might already know about the importance of water for living things. Have them suggest reasons why the runner suffered ill effects from the intake of water rather than benefiting from it. Use points made during the discussion to help students start connecting the Chapter Mystery to the Big Ideas of the Cellular Basis of Life and Homeostasis.

Have students preview the chapter vocabulary using the Flash Cards.

CHAPTER 7

Cell Structure and Function

Cellular Basis of Life, Homeostasis

Q: How are cell structures adapted to their functions?

Understanding by Design

In Unit 3, students build toward the Enduring Understanding that a cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive. In Chapter 7, students learn about the cell theory and the structure and function of parts in prokaryotic and eukaryotic cells. The graphic organizer to the right summarizes how the Big Ideas relate to the chapter Essential Question and the four lesson-level Guiding Questions.

Performance Goals

Students will build a model cell with detailed parts and explore an analogy that compares a cell to a factory. They will also analyze data about the number of mitochondria in cells of different organs. In a summative task, students will imagine themselves within a cell and write an account of how the cell functions.
Freshwater diatoms—unicellular algae with hard silica cell walls—come in many shapes and sizes (LM 880/H11547).

DEATH BY . . . WATER?
Michelle was a healthy 25-year-old running in her first marathon. The hot and humid weather had made all the runners sweat profusely, so Michelle made sure she drank water at every opportunity. Gradually, she began to feel weak and confused. At the end of the marathon, Michelle staggered into a medical tent. Complaining of headache and nausea, she collapsed onto the floor. Volunteers quickly gave Michelle water for dehydration. Soon, her condition worsened and Michelle was rushed to the hospital, where she was gripped by a seizure and went into a coma. Why did treating Michelle with water make her condition worse? As you read this chapter, look for clues to help you predict how water made Michelle sick. Then, solve the mystery.

Never Stop Exploring Your World.
Michelle’s mysterious illness is just the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

What’s Online
Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
Students use what they learn about cellular homeostasis to figure out why a runner suffered ill effects when she drank large amounts of water during a race.

UNTAMED SCIENCE VIDEO
Deep in the ocean, the Untamed Science crew explores how fishes maintain homeostasis.

VISUAL ANALOGY
Cell parts are compared with factory parts and their functions in this online activity.

ART REVIEW
Students label structures in typical plant cells and animal cells.

TUTOR TUBE
Students are reminded that plants have mitochondria in addition to chloroplasts.

INTERACTIVE ART
Explore diffusion and osmosis with an animation and an activity.

ART IN MOTION
The different types of active transport are reviewed in this short animation.

DATA ANALYSIS
Students analyze how mitochondrial function is related to human health and longevity.
The Discovery of the Cell

What is the cell theory?

“Seeing is believing,” an old saying goes. It would be hard to find a better example of this than the discovery of the cell. Without the instruments to make them visible, cells remained out of sight and, therefore, out of mind for most of human history. All of this changed with a dramatic advance in technology—the invention of the microscope.

Early Microscopes

In the late 1500s, eyeglass makers in Europe discovered that using several glass lenses in combination could magnify even the smallest objects to make them easy to see. Before long, they had built the first true microscopes from these lenses, opening the door to the study of biology as we know it today.

In 1665, Englishman Robert Hooke used an early compound microscope to look at a nonliving thin slice of cork, a plant material. Under the microscope, cork seemed to be made of thousands of tiny empty chambers. Hooke called these chambers “cells” because they reminded him of a monastery’s tiny rooms, which were called cells. The term cell is used in biology to this day. Today we know that living cells are not empty chambers, that in fact they contain a huge array of working parts, each with its own function.

In Holland around the same time, Anton van Leeuwenhoek used a single-lens microscope to observe pond water and other things. To his amazement, the microscope revealed a fantastic world of tiny living organisms that seemed to be everywhere, in the water he and his neighbors drank, and even in his own mouth. Leeuwenhoek’s illustrations of the organisms he found in the human mouth—which today we call bacteria—are shown in Figure 7–1.

Life Is Cellular

Key Questions

What is the cell theory?
How do microscopes work?
How are prokaryotic and eukaryotic cells different?

Vocabulary

cell • cell theory • cell membrane • nucleus • eukaryote • prokaryote

Taking Notes

Outline Before you read, make an outline using the green and blue headings in the text. As you read, fill in notes under each heading.

THINK ABOUT IT

What’s the smallest part of any living thing that still counts as being “alive”? Is a leaf alive? How about your big toe? How about a drop of blood? Can we just keep dividing living things into smaller and smaller parts, or is there a point at which what’s left is no longer alive? As you will see, there is such a limit, the smallest living unit of any organism—the cell.

THINK ABOUT IT

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The Discovery of the Cell

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FIGURE 7–1 Early Microscope Images Using a simple microscope, Anton van Leeuwenhoek was the first to observe living microorganisms. These drawings, taken from one of his letters, show bacteria in the human mouth.
The Cell Theory Soon after van Leeuwenhoek, observations by scientists made it clear that cells are the basic units of life. In 1838, German botanist Matthias Schleiden concluded that all plants are made of cells. The next year, German biologist Theodor Schwann stated that all animals are made of cells. In 1855, German physician Rudolf Virchow concluded that new cells can be produced only from the division of existing cells, confirming a suggestion made by German Lorenz Oken 50 years earlier. These discoveries, confirmed by many biologists, are summarized in the cell theory, a fundamental concept of biology. The cell theory states:

- All living things are made up of cells.
- Cells are the basic units of structure and function in living things.
- New cells are produced from existing cells.

Exploring the Cell

How do microscopes work?

A microscope, as you know, produces an enlarged image of something very small. Most microscopes use lenses to magnify the image of an object by focusing light or electrons. Following in the footsteps of Hooke, Virchow, and others, modern biologists still use microscopes to explore the cell. But today’s researchers use technology more powerful than the pioneers of biology could ever have imagined.

Light Microscopes and Cell Stains The type of microscope you are probably most familiar with is the compound light microscope. A typical light microscope allows light to pass through a specimen and uses two lenses to form an image. The first lens, called the objective lens, is located just above the specimen. This lens enlarges the image of the specimen. Most light microscopes have several objective lenses so that the power of magnification can be varied. The second lens, called the ocular lens, magnifies this image still further. Unfortunately, light itself limits the detail, or resolution, of images in a microscope. Like all forms of radiation, lightwaves are diffracted, or scattered, as they pass through matter. Because of this, light microscopes can produce clear images of objects only to a magnification of about 1000 times.

Another problem with light microscopy is that most living cells are nearly transparent. Using chemical stains or dyes, as in Figure 7–2, can usually solve this problem. Some of these stains are so specific that they reveal only certain compounds or structures within the cell. Many of the slides you’ll examine in your biology class laboratory will be stained this way.

A powerful variation on these staining techniques uses dyes that give off light of a particular color when viewed under specific wavelengths of light, a property called fluorescence. Fluorescent dyes can be attached to specific molecules and can then be made visible using a special fluorescence microscope. New techniques, in fact, enable scientists to engineer cells that attach fluorescent labels of different colors to specific molecules as they are produced. Fluorescence microscopy makes it possible to see and identify the locations of these molecules and even allows scientists to watch them move around in a living cell.

Quick Facts

SCANNING PROBE MICROSCOPY

Like scanning electron microscopes, scanning probe microscopes form images of surfaces. Scanning probe microscopes use a sharply pointed probe to scan samples. This type of microscope includes scanning tunneling microscopes (STM) and atomic force microscopes (AFM). An STM probe does not quite touch a sample. Instead, an electric current between the probe and the surface of the specimen tracks the topography of the surface. This technique is limited to specimens that are good conductors. The limitation was overcome in 1985, when the AFM was introduced. The AFM can image almost any type of surface and has several modes of operation, making it very versatile. In the contact mode, the probe of an AFM gently touches the sample surface in a way similar to the needle used on an LP record. The needle slides over the surface of the sample without causing damage and sends data about the surface to a processor.

Teach

Lead a Discussion

Have students create a time line of dates, people, and events leading to the development of the cell theory. Then, ask the following questions.

Ask What are some ways the discovery of new ideas can take place? (Sample answer: Some discoveries come about as new technologies are developed.)

Ask What technology helped in the discovery of cells? (the microscope)

Ask What are the three parts of the cell theory? (All living things are made up of cells; cells are the basic units of structure and function in living things; new cells are produced from existing cells.)

Differently abled

Less Proficient Readers Have pairs of students make a T-Chart to organize information from the text about using microscopes and stains. Have them label the left side of the chart Technology and the right side Benefits and write Light Microscope and Stain in rows under Technology. They can complete the chart by writing one benefit in the right column opposite each technology. (Sample answer: Light Microscope, enlarged image; Stain, makes cell parts visible)

Study Wkbks A/B, Appendix S30, T-Chart. Transparencies, GO15.

Focus on ELL: Build Background

BEGINNING AND ADVANCED SPEAKERS To access students’ prior knowledge, begin by writing the word cell on the board. Explain to students that the word cell has many meanings, but in this exercise they should concentrate on the biological meaning. Say the word aloud, and then have ELL students pronounce it. Ask students to say words and phrases they associate with the word cell. Write the answers in the form of a Cluster Diagram around the word cell. If students do not volunteer the three parts of the cell theory, write them on the diagram yourself.

LESSON 7.1

Contrast Table.

Study Wkbks A/B, Appendix S20, Compare/Contrast the table. Have students fill in the missing information in the text to learn, specifically, the characteristics of different types of microscopes. Then, supply students with a partially completed Compare/Contrast Table that identifies the type of microscope (light, transmission electron, or scanning electron), whether it forms surface or interior images, and what its limitations are. Have students look at other photos in this chapter and identify the types of microscopes used to create the images from information in the captions.

DIFFERENTIATED INSTRUCTION

LPR Less Proficient Readers Have students reread the text to learn, specifically, the characteristics of different types of microscopes. Then, supply students with a partially completed Compare/Contrast Table that identifies the type of microscope (light, transmission electron, or scanning electron), whether it forms surface or interior images, and what its limitations are. Have students fill in the missing information in the table.

Study Wkbks A/B, Appendix S20, Compare/Contrast Table. Transparencies, GO3.

Ubd Check for Understanding

HAND SIGNALS

Write the following questions on the board. Ask students to show a thumbs-up sign if they know and understand the topic, a thumbs-down sign if they don’t know or are confused about it, or a waving-hand sign if they understand it partially.

• What are the three parts of the cell theory?
• How does a light microscope magnify an image?
• Name one difference between a transmission and a scanning electron microscope.

ADJUST INSTRUCTION

If more than one student has difficulty with a question, have the class work together to rephrase the concept as it is discussed in the text and then write a short response to the question.

Answers

FIGURE 7–3 Scientists would most likely use a scanning electron microscope.

IN YOUR NOTEBOOK Sample answer: Is the specimen alive? What is to be observed—the surface of the specimen or the internal structures of the specimen?
Prokaryotes and Eukaryotes

How are prokaryotic and eukaryotic cells different?

Cells come in an amazing variety of shapes and sizes, some of which are shown in Figure 7–4. Although typical cells range from 5 to 50 micrometers in diameter, the smallest Mycoplasma bacteria are only 0.2 micrometer across, so small that they are difficult to see under even the best light microscopes. In contrast, the giant amoeba Chaos chaos can be 1000 micrometers (1 millimeter) in diameter, large enough to be seen with the unaided eye as a tiny speck in pond water. Despite their differences, all cells, at some point in their lives, contain DNA, the molecule that carries biological information. In addition, all cells are surrounded by a thin flexible barrier called a cell membrane. (The cell membrane is sometimes called the plasma membrane because many cells in the body are in direct contact with the fluid portion of the blood—the plasma.) There are other similarities as well, as you will learn in the next lesson.

Cells fall into two broad categories, depending on whether they contain a nucleus. The nucleus (plural: nuclei) is a large membrane-enclosed structure that contains genetic material in the form of DNA and controls many of the cell’s activities. Eukaryotes (yoo kar ee ohts) are cells that enclose their DNA in nuclei. Prokaryotes (pro kar ee ohts) are cells that do not enclose DNA in nuclei.

**FIGURE 7–4 Cell Size Is Relative**
The human eye can see objects larger than about 0.5 mm. Most of what interests cell biologists, however, is much smaller than that. Microscopes make seeing the cellular and subcellular world possible.

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** Call students’ attention to the conversion table on the right side of Figure 7–4. Go over this conversion scale, explaining all the conversions, e.g., that one nanometer is equal to one one-billionth of a meter. It may help to reverse the relationship, i.e., to explain that one meter contains one billion nanometers and one million micrometers.

To help students understand the actual relationship in size between some of the items in the illustration, you might draw a typical prokaryotic cell and a typical eukaryotic cell to scale on a large sheet of paper. Use circles to represent the cells. To represent the prokaryotic cell, draw a circle with a diameter of 0.5 cm. For the eukaryotic cell, draw a circle with a diameter of 25 cm.

**ANALYZE AND CONCLUDE**

1. Accept all classifications that are supported by logical reasons. Sample answer: Plant Cells (leaf and stem cells): green structures, thick cell walls, visible nucleus; Animal Cells (nerve cells): more irregular shape than plant cells, visible nucleus, no green structures; Single-Celled Organisms (bacteria and paramecia): appear more flexible than plant cells, no green structures.

Students should infer that a light microscope was probably used to study the blood sample, because the focus was on cells rather than smaller objects such as viruses. For a hint of what red blood cells look like under various conditions of hydration, students can turn to Figure 7–18. Students also can go online to Biology.com to gather evidence.
Elec- and the first paragraph under Cell Stains first paragraph under Question 2, ble with help them focus on individual cell parts.

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** Alert students that these same images will appear throughout Lesson 7.2 to help them focus on individual cell parts.

**Assess and Remediate**

**EVALUATE UNDERSTANDING**

Have students construct **Venn Diagrams** comparing light microscopes and electron microscopes. Then, have them complete the 7.1 Assessment.

**Study Wkbks A/B**, Appendix S33, Venn Diagram. Transparencies, GO18.

**REMEDIATION SUGGESTION**

**Struggling Students** If students have trouble with Question 2, direct them to reread the first paragraph under **Light Microscopes and Cell Stains** and the first paragraph under **Electron Microscopes**.

**Assessment Answers**

1a. the basic unit of life

1b. All living things are made up of cells. Cells are the basic units of structure and function in living things. New cells are produced from existing cells.

1c. The microscope enabled people to see cells and study the parts of cells. This ability enabled scientists to learn that all organisms are composed of cells.

2a. Microscopes contain lenses, which focus light or electrons to produce an enlarged image of something that is otherwise too small to see.

2b. False coloring is sometimes added to electron micrographs by computers to make certain structures easier to see.

3a. All cells have DNA at some time in their lives, and all cells are surrounded by a thin, flexible cell membrane.

3b. Prokaryotes do not have DNA enclosed in a nucleus. Eukaryotes have DNA enclosed in a nucleus.

**Prokaryotes** As seen in Figure 7–5, prokaryotic cells are generally smaller and simpler than eukaryotic cells, although there are many exceptions to this rule. Prokaryotic cells do not separate their genetic material within a nucleus. Despite their simplicity, prokaryotes carry out every activity associated with living things. They grow, reproduce, respond to the environment, and, in some cases, glide along surfaces or swim through liquids. The organisms we call bacteria are prokaryotes.

**Eukaryotes** Eukaryotic cells are generally larger and more complex than prokaryotic cells. Most eukaryotic cells contain dozens of structures and internal membranes, and many are highly specialized. In eukaryotic cells, the nucleus separates the genetic material from the rest of the cell. Eukaryotes display great variety: some, like the ones commonly called “protists,” live solitary lives as unicellular organisms; others form large, multicellular organisms—plants, animals, and fungi.

**Figure 7–5 Cell Types** In general, eukaryotic cells (including plant and animal cells) are more complex than prokaryotic cells.
Cells are the basic unit of all known life. If cells interest you, you might want to consider one of the following careers.

LABORATORY TECHNICIAN
Ever wonder what happens to the blood your doctor collects during your annual physical? It goes to a laboratory technician. Laboratory technicians perform routine procedures using microscopes, computers, and other equipment. Many laboratory technicians work in the medical field, evaluating and analyzing test results.

MICROSCOPIST
The images in Figure 7–3 were captured by a microscopist. Microscopists make it possible to study structures too small to be seen without magnification. There are a variety of microscopy techniques, including staining and fluorescence, that microscopists can use to make images clear and informative for researchers. Some of these images are so striking that they have become a form of scientific art.

PATHOLOGIST
Pathologists are like detectives: They collect cellular information and tissue evidence to diagnose illness. Using a broad knowledge of disease characteristics and the best-available technology, pathologists analyze cells and tissues under a microscope and discuss their diagnoses with other doctors.

CAREER CLOSE-UP
Dr. Tanasa Osborne, Veterinary Pathologist
Dr. Tanasa Osborne studies osteosarcoma, the most common malignant bone tumor in children and adolescents. Her research with the National Institutes of Health and the National Cancer Institute is focused on improving outcomes for patients whose cancer has spread from one organ or system to another. Dr. Osborne is not a medical doctor, however—she is a veterinarian. Animals are often used as models to study human disease. Dr. Osborne’s research, therefore, contributes to both animal and human health. Veterinary pathologists investigate many important issues in addition to cancer, including West Nile virus, avian flu, and other emerging infectious diseases that affect humans as well as animals.

“My distinctive background allows me to approach science from a global (or cross-species) and systemic perspective.”

DIFFERENTIATED INSTRUCTION
ELL English Language Learners Have students select one of the following terms: microscopist, pathologist, technician, or veterinarian. Then, ask them to work in pairs to find the meaning of the word. The pairs should collaborate on constructing a Vocabulary Word Map to help them remember the definition of the term. Have them write the word in the top box and attributes of the word in the lower boxes. For example, attributes for microscopist might include “works with microscopes,” “creates clear images,” “may use stains,” and “may use fluorescence.”

Study Wkbks A/B, Appendix S32, Vocabulary Word Map. Transparencies, G017.

Quick Facts
BECOMING A FORENSIC PATHOLOGIST
Forensic pathology is one branch of pathology. A forensic pathologist is a highly trained medical doctor who performs autopsies to determine cause of death, usually in connection with criminal or legal investigations. Forensic pathologists biopsy tissues and analyze blood to determine the time and manner of death, including whether death was natural or caused by injury. Forensic pathologists work for cities, counties, states, the military, and hospitals. While most forensic pathologists autopsy dead persons, some clinical forensic pathologists examine and collect tissue samples from live victims of crime.

Those interested in forensic pathology as a career are encouraged to take all the basic sciences, such as biology, chemistry, and physics. College is followed by four years of medical school, four to five years of training in pathology, and on-the-job training.

Answers
WRITING Answers will vary. Students may mention that Dr. Osborne’s research has the potential to help in the treatment of cancer in humans. Therefore, her research can benefit society.

NATIONAL SCIENCE EDUCATION STANDARDS
UCP I, II
CONTENT E.2, F.6, G.1
INQUIRY A.2.b, A.2.c, A.2.f
Getting Started

Objectives

7.2.1 Describe the structure and function of the cell nucleus.
7.2.2 Describe the role of vacuoles, lysosomes, and the cytoskeleton.
7.2.3 Identify the role of ribosomes, endoplasmic reticulum, and Golgi apparatus in making proteins.
7.2.4 Describe the function of the chloroplasts and mitochondria in the cell.
7.2.5 Describe the function of the cell membrane.

Student Resources

Study Workbooks A and B, 7.2 Worksheets
Spanish Study Workbook, 7.2 Worksheets
Lab Manual A, 7.2 Quick Lab Worksheet
Lab Manual B, 7.2 Hands-On Activity Worksheet

For corresponding lesson in the Foundation Edition, see pages 164–175.

Cell Structure

THINK ABOUT IT
At first glance, a factory is a puzzling place. Machines buzz and clatter; people move quickly in different directions. So much activity can be confusing. However, if you take the time to watch carefully, what might at first seem like chaos begins to make sense. The same is true for the living cell.

Cell Organization

What is the role of the cell nucleus?
The eukaryotic cell is a complex and busy place. But if you look closely at eukaryotic cells, patterns begin to emerge. For example, it’s easy to divide each cell into two major parts: the nucleus and the cytoplasm. The cytoplasm is the portion of the cell outside the nucleus. As you will see, the nucleus and cytoplasm work together in the business of life. Prokaryotic cells have cytoplasm too, even though they do not have a nucleus.

In our discussion of cell structure, we consider each major component of plant and animal eukaryotic cells—some of which are also found in prokaryotic cells—one by one. Because many of these structures act like specialized organs, they are known as organelles, literally “little organs.” Understanding what each organelle does helps us understand the cell as a whole. A summary of cell structure can be found on pages 206–207.

Cell Structure

Key Questions

- What is the role of the cell nucleus?
- What are the functions of vacuoles, lysosomes, and the cytoskeleton?
- What organelles help make and transport proteins?
- What are the functions of chloroplasts and mitochondria?
- What is the function of the cell membrane?

Vocabulary

cytoplasm • organelle • vacuole • lysosome • cytoskeleton • centriole • ribosome • endoplasmic reticulum • Golgi apparatus • chloroplast • mitochondrion • cell wall • lipid bilayer • selectively permeable

Taking Notes

Venn Diagram Create a Venn diagram that illustrates the similarities and differences between prokaryotes and eukaryotes.

Visual Analogy

THE CELL AS A LIVING FACTORY

FIGURE 7–6 The specialization and organization of work and workers contribute to the productivity of a factory. In much the same way, the specialized parts in a cell contribute to the cell’s overall stability and survival.

Teach for Understanding

ENDURING UNDERSTANDING A cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive.

GUIDING QUESTION How do cell structures enable a cell to carry out basic life processes?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how cell structures enable them to carry out life processes. Provide each student with an unlabeled copy of the cells in Figure 7–14. Have them work in pairs to identify each type of cell, label the structures of each cell, and write a function for each cell part.
Comparing the Cell to a Factory  In some respects, the eukaryotic cell is much like a living version of a modern factory (Figure 7–6). The different organelles of the cell can be compared to the specialized machines and assembly lines of the factory. In addition, cells, like factories, follow instructions and produce products. As we look through the organization of the cell, we’ll find plenty of places in which the comparison works so well that it will help us understand how cells work.

The Nucleus  In the same way that the main office controls a large factory, the nucleus is the control center of the cell. The nucleus contains nearly all the cell's DNA and, with it, the coded instructions for making proteins and other important molecules. Prokaryotic cells lack a nucleus, but they do have DNA that contains the same kinds of instructions.

The nucleus, shown in Figure 7–7, is surrounded by a nuclear envelope composed of two membranes. The nuclear envelope is dotted with thousands of nuclear pores, which allow material to move into and out of the nucleus. Like messages, instructions, and blueprints moving in and out of a factory’s main office, a steady stream of proteins, RNA, and other molecules move through the nuclear pores to and from the rest of the cell.

Chromosomes, which carry the cell’s genetic information, are also found in the nucleus. Most of the time, the threadlike chromosomes are spread throughout the nucleus in the form of chromatin—a complex of DNA bound to proteins. When a cell divides, its chromosomes condense and can be seen under a microscope. You will learn more about chromosomes in later chapters.

Most nuclei also contain a small dense region known as the nucleolus. The nucleolus is where the assembly of ribosomes begins.

In Your Notebook  Describe the structure of the nucleus. Include the words nuclear envelope, nuclear pore, chromatin, chromosomes, and nucleolus in your description.
Organelles That Store, Clean Up, and Support

**What are the functions of vacuoles, lysosomes, and the cytoskeleton?**

Many of the organelles outside the nucleus of a eukaryotic cell have specific functions, or roles. Among them are structures called vacuoles, lysosomes, and cytoskeleton. These organelles represent the cellular factory’s storage space, cleanup crew, and support structures.

**Vacuoles and Vesicles** Every factory needs a place to store things, and so does every cell. Many cells contain large, saclike, membrane-enclosed structures called vacuoles. Vacuoles store materials like water, salts, proteins, and carbohydrates. In many plant cells, there is a single, large central vacuole filled with liquid. The pressure of the central vacuole in these cells increases their rigidity, making it possible for plants to support heavy structures, such as leaves and flowers. The image on the left in Figure 7–8 shows a typical plant cell’s large central vacuole.

Vacuoles are also found in some unicellular organisms and in some animals. The paramecium on the right in Figure 7–8 contains an organelle called a contractile vacuole. By contracting rhythmically, this specialized vacuole pumps excess water out of the cell. In addition, nearly all eukaryotic cells contain smaller membrane-enclosed structures called vesicles. Vesicles store and move materials between cell organelles, as well as to and from the cell surface.

**Lysosomes** Even the neatest, cleanest factory needs a cleanup crew, and that’s where lysosomes come in. Lysosomes are small organelles filled with enzymes. Lysosomes break down lipids, carbohydrates, and proteins into small molecules that can be used by the rest of the cell. They are also involved in breaking down organelles that have outlived their usefulness. Lysosomes perform the vital function of removing “junk” that might otherwise accumulate and clutter up the cell. A number of serious human diseases can be traced to lysosomes that fail to function properly. Biologists once thought that lysosomes were only found in animal cells, but it is now clear that lysosomes are also found in a few specialized types of plant cells as well.

**DIFFERENTIATED INSTRUCTION**

**L5 Special Needs** Tell students that a model often makes something easier to understand. Make a model of a plant’s central vacuole (shown in Figure 7–8) by placing a small inflated balloon inside a small plastic food container. Ask students to recall what plant cells store in their vacuoles. (water, salts, proteins, and carbohydrates)

**LPR Less Proficient Readers** To help students focus on the important information in this lesson, ask them to write the Key Questions in their notebooks. Have them find the answers as they read, and write them in their notebooks.

**Answers**

**FIGURE 7–8** The pressure of the liquid in the vacuoles makes the plant rigid, which allows it to hold up stems, leaves, and flowers.
The Cytoskeleton  As you know, a factory building is supported by steel or cement beams and by columns that hold up its walls and roof. Eukaryotic cells are given their shape and internal organization by a network of protein filaments known as the cytoskeleton. Certain parts of the cytoskeleton also help transport materials between different parts of the cell, much like the conveyor belts that carry materials from one part of a factory to another. Cytoskeletal components may also be involved in moving the entire cell as in cell flagella and cilia. The cytoskeleton helps the cell maintain its shape and is also involved in movement. Fluorescence imaging, as seen in Figure 7–9, clearly shows the complexity of a cell’s cytoskeletal network. Microfilaments (pale purple) and microtubules (yellow) are two of the principal protein filaments that make up the cytoskeleton.

Microfilaments  Microfilaments are threadlike structures made up of a protein called actin. They form extensive networks in some cells and produce a tough flexible framework that supports the cell. Microfilaments also help cells move. Microfilament assembly and disassembly are responsible for the cytoplasmic movements that allow amoebas and other cells to crawl along surfaces.

Microtubules  Microtubules are hollow structures made up of proteins known as tubulins. In many cells, they play critical roles in maintaining cell shape. Microtubules are also important in cell division, where they form a structure known as the mitotic spindle, which helps to separate chromosomes. In animal cells, organelles called centrioles are also formed from tubulins. Centrioles are located near the nucleus and help organize cell division. Centrioles are not found in plant cells.

Microtubules also help build projections from the cell surface—known as cilia (singular: cilium) and flagella (singular: flagellum)—that enable cells to swim rapidly through liquid. The microtubules in cilia and flagella are arranged in a “9 + 2” pattern, as shown in Figure 7–10. Small cross-bridges between the microtubules in these organelles use chemical energy to pull on, or slide along, the microtubules, producing controlled movements.

Apply Concepts  What is the function of cilia?

Cell Structure and Function 199

Figure 7–8  Cilia project from cells and enable them to move through liquids.

Lead a Discussion  Ask students if they have ever been inside a circus tent. Have them describe the structure of the tent, including the poles and extensive networks of ropes and guy wires. Ask students to suggest what those structures are used for. Draw students’ attention to Figure 7–9. Explain that cells have an extensive network of filaments in the cytoplasm called the cytoskeleton.

Ask students to suggest how some of the functions of their own skeleton (shape, support, and movement) might help them understand the function of a cell’s cytoskeleton.

DIFFERENTIATED INSTRUCTION

Less Proficient Readers  Pair struggling readers with more proficient readers to construct a Concept Map of the information on this page to show the relationship between the cytoskeleton, microfilaments, and microtubules.

Study Wkbks A/B, Appendix S21, Concept Map. Transparencies, GO4.

Advanced Students  Extend the content of this topic by having students independently research how the cytoskeleton was discovered and how its discovery is connected with developments in microscopy. Ask students to share what they learn with the class.

Answers

FIGURE 7–8  Cilia project from cells and enable them to move through liquids.
**Build Study Skills**

Prepare students to understand the importance of proteins and the complex process by which they are made in cells by using a Directed Reading-Thinking Activity. First, tell students to skim the section titled, *Organelles That Build Proteins*, looking at the headings, the highlighted vocabulary terms, and Figure 7–11. Then, have students predict what the text will be about. Finally, have them read the section and verify their predictions with specific sentences from the text. Students should conclude the exercise by writing what they have learned.

**Study Wkbks A/B**, Appendix S5, Directed Reading-Thinking Activity.

**DIFFERENTIATED INSTRUCTION**

**LPR Less Proficient Readers** For students who are overwhelmed by applying the Directed Reading-Thinking Activity to all the text on these two pages, have them begin by focusing on ribosomes. Assist them by drawing their attention to the blue heading, *Ribosomes*. Show them that this heading gives them a clue about what the text that follows the heading will explain. After students have skimmed the text about ribosomes and Figure 7–11, made their predictions, and written what they have learned, ask them to identify the function of ribosomes. (*Ribosomes produce proteins according to a code derived from DNA.*)

**Check for Understanding**

**QUESTION BOX**

Provide a box into which students can put their questions about ribosomes and the endoplasmic reticulum. Encourage students to write questions about aspects of the text that they do not understand.

**ADJUST INSTRUCTION**

If most students write essentially the same questions, discuss these topics with the class as a whole. Answer the questions, referring to specific content in the text and Figure 7–11. Then, to determine whether students now understand the concepts, ask volunteers to explain the answers to the questions in their own words. Work with students individually or in small groups to address any topics that only a few students do not comprehend.
Proteins made on the rough ER include those that will be released, or secreted, from the cell as well as many membrane proteins and proteins destined for lysosomes and other specialized locations within the cell. Rough ER is abundant in cells that produce large amounts of protein for export. Other cellular proteins are made on “free” ribosomes, which are not attached to membranes.

The other portion of the ER is known as smooth endoplasmic reticulum (smooth ER) because ribosomes are not found on its surface. In many cells, the smooth ER contains collections of enzymes that perform specialized tasks, including the synthesis of membrane lipids and the detoxification of drugs. Liver cells, which play a key role in detoxifying drugs, often contain large amounts of smooth ER.

**Golgi Apparatus** In eukaryotic cells, proteins produced in the rough ER move next into an organelle called the **Golgi apparatus,** which appears as a stack of flattened membranes. As proteins leave the rough ER, molecular “address tags” get them to the right destinations. As these tags are “read” by the cell, the proteins are bundled into tiny vesicles that bud from the ER and carry them to the Golgi apparatus. The **Golgi apparatus modifies, sorts, and packages proteins and other materials from the endoplasmic reticulum for storage in the cell or release outside the cell.** The Golgi apparatus is somewhat like a customization shop, where the finishing touches are put on proteins before they are ready to leave the “factory.” From the Golgi apparatus, proteins are “shipped” to their final destination inside or outside the cell.

![Image: Cell Structure and Function 201](image)

**Quick Facts**

**WHAT HAPPENS WITHIN THE GOLGI APPARATUS?**

In a cell, the Golgi apparatus is analogous to a person who takes a product that has been only roughly manufactured and, with hundreds of separate orders to fill, finishes off the rough edges, makes requested changes, and turns out products that meet specific individual orders. The Golgi apparatus has two general regions: the cis end and the trans end. The end closer to the endoplasmic reticulum is referred to as the cis end. It receives materials from the ER enclosed in membranous vesicles. The vesicles deliver their newly manufactured proteins by fusing with the membranes of the cis end. The materials are then passed through the layers, or cisternae, of the Golgi apparatus. They leave from the opposite, or trans, end, which is farther away from the ER. In transit, the proteins are modified and finished by enzymes before being distributed. Materials that will leave the cell are packed in vesicles that bud off from the Golgi apparatus and eventually fuse with the cell membrane.

**VISUAL SUMMARY**

Making Proteins

**FIGURE 7–11** Together, ribosomes, the endoplasmic reticulum, and the Golgi apparatus synthesize, modify, package, and ship proteins. Infer: What can you infer about a cell that is packed with more than the typical number of ribosomes?

**DIFFERENTIATED INSTRUCTION**

**LPR Less Proficient Readers** Explain to students that an important part of reading comprehension is taking note of art and using it to understand what is written in the text. Point out that Figure 7–11 summarizes the process of protein assembly and export in a series of numbered steps. Tell students that they can use these steps to help them understand the section, Organelles That Build Proteins, and to complete the In Your Notebook.

**Answers**

**FIGURE 7–11** Ribosomes are sites of protein production. When a cell has more than the typical number of ribosomes, you might infer that it produces more proteins than other cells.

**IN YOUR NOTEBOOK** Flowcharts should summarize the steps in Figure 7–11.
LESSON 7.2

Lead a Discussion

Make sure students understand how important energy is to living things. Discuss why chloroplasts might be referred to as “solar collectors” and mitochondria as “power plants.” Have students discuss why animals must consume food to obtain energy, whereas plants are able to produce their own food, using energy from sunlight.

DIFFERENTIATED INSTRUCTION

Less Proficient Readers Ask students to preview the first three paragraphs on this page, keeping in mind the following questions:

- Which organelle captures energy from sunlight and converts it to chemical energy in cells? (chloroplast)
- Which organelle converts or releases chemical energy from food in cells? (mitochondrion)

Address Misconceptions

Mitochondria and Chloroplasts Some students may think that mitochondria are found only in animal cells and chloroplasts are found only in plant cells. Clarify that mitochondria are found in nearly all eukaryotes, including plants. Chloroplasts are found outside of the plant clade, in photosynthetic “pro-tists,” such as red and brown algae and euglenas. Try to get students to associate mitochondria and chloroplasts with their function—eukaryotes that undergo cellular respiration have mitochondria, and eukaryotes that undergo photosynthesis have chloroplasts and mitochondria. Therefore, plants, which undergo both processes, have both types of organelles, while animals have only mitochondria.

Answers

FIGURE 7–12 The cell is a plant cell, because it contains chloroplasts.

Organelles That Capture and Release Energy

What are the functions of chloroplasts and mitochondria? All living things require a source of energy. Factories are hooked up to the local power company, but how do cells get energy? Most cells are powered by food molecules that are built using energy from the sun.

Chloroplasts Plants and some other organisms contain chloroplasts (klawr uh plasts). Chloroplasts are the biological equivalents of solar power plants. Chloroplasts capture the energy from sunlight and convert it into food that contains chemical energy in a process called photosynthesis. Two membranes surround chloroplasts. Inside the organelle are large stacks of other membranes, which contain the green pigment chlorophyll.

Mitochondria Nearly all eukaryotic cells, including plants, contain mitochondria (myt oh kahn dree uh; singular: mitochondrion). Mitochondria are the power plants of the cell. Mitochondria convert the chemical energy stored in food into compounds that are more convenient for the cell to use. Like chloroplasts, two membranes—an outer membrane and an inner membrane—enclose mitochondria. The inner membrane is folded up inside the organelle, as shown in Figure 7–12.

One of the most interesting aspects of mitochondria is the way in which they are inherited. In humans, all or nearly all of our mitochondria come from the cytoplasm of the ovum, or egg cell. This means that when your relatives are discussing which side of the family should take credit for your best characteristics, you can tell them that you got your mitochondria from Mom!

Another interesting point: Chloroplasts and mitochondria contain their own genetic information in the form of small DNA molecules. This observation has led to the idea that they may be descended from independent microorganisms. This idea, called the endosymbiotic theory, is discussed in Chapter 19.

Quick Facts

MITOCHONDRIAL DISEASES

The health of an individual organism depends on the health of its organelles. For example, defects in mitochondria cause some forms of deafness, blindness, and diseases that affect muscles and nerves. Cells are dependent on energy that is normally released by chemical reactions in mitochondria. Many mitochondrial diseases affect muscles, which may have thousands of mitochondria in each cell. If mitochondria lack oxidative-phosphorylation enzymes, toxic substances accumulate, and energy cannot be released from food. The muscle weakness that appears in muscular dystrophy is related to defective mitochondria. Other conditions related to mitochondrial dysfunctions are retinitis pigmentosa, diabetes mellitus, and some forms of deafness. Mitochondrial diseases can result from mutations in nuclear DNA or mitochondrial DNA.
**Cellular Boundaries**

**What is the function of the cell membrane?**

A working factory needs walls and a roof to protect it from the environment outside, and also to serve as a barrier that keeps its products safe and secure until they are ready to be shipped out. Cells have similar needs, and they meet them in a similar way. As you have learned, all cells are surrounded by a barrier known as the cell membrane. Many cells, including most prokaryotes, also produce a strong supporting layer around the membrane known as a **cell wall**.

**Cell Walls**

Many organisms have cell walls in addition to cell membranes. The main function of the cell wall is to support, shape, and protect the cell. Most prokaryotes and many eukaryotes have cell walls. Animal cells do not have cell walls. Cell walls lie outside the cell membrane. Most cell walls are **porous** enough to allow water, oxygen, carbon dioxide, and certain other substances to pass through easily.

Cell walls provide much of the strength needed for plants to stand against the force of gravity. In trees and other large plants, nearly all of the tissue we call wood is made up of cell walls. The cellulose fiber used for paper as well as the lumber used for building comes from these walls. So if you are reading these words off a sheet of paper from a book resting on a wooden desk, you’ve got cell walls all around you.

**BUILD Vocabulary**

**ACADEMIC WORDS** The adjective **porous** means “allowing materials to pass through.” A porous cell wall allows substances like water and oxygen to pass through it.

---

**Quick Lab**

**Making a Model of a Cell**

1. Your class is going to make a model of a plant cell using the whole classroom. Work with a partner or in a small group to decide what cell part or organelle you would like to model. (Use Figure 7–14 on pages 206–207 as a starting point. It gives you an idea of the relative sizes of various cell parts and their possible positions.)

2. Using materials of your choice, make a three-dimensional model of the cell part or organelle you chose. Make the model as complete and as accurate as you can.

3. Label an index card with the name of your cell part or organelle, and list its main features and functions. Attach the card to your model.

4. Attach your model to an appropriate place in the room. If possible, attach your model to another related cell part or organelle.

**Analyze and Conclude**

1. **Calculate** Assume that a typical plant cell is 50 micrometers wide (50 × 10⁻⁶ m). Calculate the scale of your classroom cell model. (Hint: Divide the width of the classroom by the width of a cell, making sure to use the same units.) **Hint**

2. **Compare and Contrast** How is your model cell part or organelle similar to the real cell part or organelle? How is it different?

3. **Evaluate** Based on your work with this model, describe how you could make a better model. What new information would your improved model demonstrate?

---

**Analyse and Conclude**

1. Scales will vary depending on the size of the classroom. If a room is 5 m (500,000,000 micrometers) across and a typical cell is 50 micrometers across, the scale would be 1,000,000 : 1.

2. Model organelles and cell parts should be similar in shape and structure to the real objects. The models are different in that they are much larger, are made of different materials, and do not function.

3. Students should suggest ways to make better models than the original ones.

---

**Lead a Discussion**

Ask students to consider what happens when a property owner puts up a fence. What purpose does the fence serve? How do people get in and out? Are there different kinds of fences? Use the analogy to explain that a cell’s contents are also confined within a barrier. Have students use the reduced cell images on this page and the larger version in Figure 7–14 to find out which cells have cell walls and where cell walls are located in cells. Then, write this prompt on the board, and have students defend or refute it: All cells have a cell membrane, but not all cells have a cell wall.

**Differentiated Instruction**

**L1 Special Needs**

If students do not understand the analogy comparing cell membranes/walls to fences, show a photograph or illustration of a fence. Ask students what the function of the fence is. (A fence keeps some things inside and other things outside.) Then, refer students to Figure 7–14.

**Ask** Where are the cell membrane and cell wall found? (on the outside edge of the cell, surrounding the cell contents)

**Ask** Do you think the mitochondria, nucleus, and other organelles can cross the cell membrane? (no)

**L2 Advanced Students**

Have students find out what chemical compound is most commonly found in cell walls that makes certain plants useful for building materials and paper making. (cellulose) Have them describe their findings in writing.
Cell Membranes
All cells contain cell membranes, which almost always are made up of a double-layered sheet called a lipid bilayer. As shown in Figure 7–13, the lipid bilayer gives cell membranes a flexible structure that forms a strong barrier between the cell and its surroundings. The cell membrane regulates what enters and leaves the cell and also protects and supports the cell.

The Properties of Lipids
The layered structure of cell membranes reflects the chemical properties of the lipids that make them up. You may recall that many lipids have oily fatty acid chains attached to chemical groups that interact strongly with water. In the language of a chemist, the fatty acid portions of this kind of lipid are hydrophobic (hy druh fik), or “water-hating,” while the opposite end of the molecule is hydrophilic (hy druh fil ihk), or “water-loving.” When these lipids, including the phospholipids that are common in animal cell membranes, are mixed with water, their hydrophobic fatty acid “tails” cluster together while their hydrophilic “heads” are attracted to water. A lipid bilayer is the result. As you can see in Figure 7–13, the head groups of lipids in a bilayer are exposed to the outside of the cell, while the fatty acid tails form an oily layer inside the membrane that keeps water out.

ThiM 6250
Hydrophilic head
Hydrophobic tail
Carbohydrate chain

Lipid Bilayer

Cell membrane

OUTSIDE
OF
CELL

INSIDE
OF
CELL

(CYTOPLASM)

Apply Concepts
Explain why lipids “self-assemble” into a bilayer when exposed to water.

**DIFFERENTIATED INSTRUCTION**

**L3 Special Needs**
Make sure that students understand the relationship between the different components of Figure 7–13 and also the perspective shown by the illustration. Clarify that the illustration shows a tiny part of a cell membrane, similar to the membrane that surrounds the cell in the micrograph. Explain that the illustration is a cross section. To model a cross section, you might cut a lemon or orange in half and show how the cut reveals a cross section of the rind. Finally, show how you can tell, by looking at the “whoosh” in the illustration, that the lipid molecule is an enlargement of one tiny part of the cross section of the membrane.

**L3 Advanced Students**
Have students work in pairs to develop an analogy related to the fluid mosaic model. Emphasize that the protein and lipid molecules in the membrane can move.

**Check for Understanding**

**ONE-MINUTE RESPONSE**

Give students one minute to write a response to:

- How do cell membranes regulate what enters and leaves the cell, and how do they protect the cell? (Cell membranes are selectively permeable, which means that some materials can enter them, but some are too large or too strongly charged. Keeping out or expelling some materials is a form of protection.)

**ADJUST INSTRUCTION**

If responses show that students are confused by the role of the cell membrane, suggest they work in pairs to discuss what might happen to a cell that did not have a selectively permeable membrane. Then, ask pairs to rewrite a response to the question.

**Answers**

**FIGURE 7–13** The hydrophobic end of the lipid molecules turns away from water molecules, but the hydrophilic end of lipid molecules is attracted to water molecules both inside and outside the cell. With water on both sides, a two-layer, or bilayer, system of lipid molecules forms, with the phobic portions within the membrane.
The Fluid Mosaic Model

Embedded in the lipid bilayer of most cell membranes are protein molecules. Carbohydrate molecules are attached to many of these proteins. Because the proteins embedded in the lipid bilayer can move around and “float” among the lipids, and because so many different kinds of molecules make up the cell membrane, scientists describe the cell membrane as a “fluid mosaic.” A mosaic is a kind of art that involves bits and pieces of different colors or materials. What are all these different molecules doing? As you will see, some of the proteins form channels and pumps that help to move material across the cell membrane. Many of the carbohydrate molecules act like chemical identification cards, allowing individual cells to identify one another. Some proteins attach directly to the cytoskeleton, enabling cells to respond to their environment by using their membranes to help move or change shape.

As you know, some things are allowed to enter and leave a factory, and some are not. The same is true for living cells. Although many substances can cross biological membranes, some are too large or too strongly charged to cross the lipid bilayer. If a substance is able to cross a membrane, the membrane is said to be permeable to it. A membrane is impermeable to substances that cannot pass across it. Most biological membranes are selectively permeable, meaning that some substances can pass across them and others cannot. Selectively permeable membranes are also called semipermeable membranes.

membranes are also called semipermeable membranes.stances can pass across them and others cannot. Selectively permeable/H17075
**Teach**

**VISUAL SUMMARY**

Use Figure 7–14 to review the parts of typical cells. Divide the class into small groups, and have each group submit a question about a cell function to be answered by the class. Answers should incorporate specific vocabulary terms shown in the figure.

**DIFFERENTIATED INSTRUCTION**

**LPR Less Proficient Readers** Pair less proficient readers with proficient readers. Have students use Figure 7–14 to write questions on index cards about cell parts and then use the cards to quiz each other without looking at the table on the opposite page. (*Sample question: What cell part enables a cell to release energy?) Collect the cards, and use them for a class review.

**L3 Advanced Students** Have interested students conduct research and draw labeled models of typical fungi and protist cells. Hang their drawings on the wall for other students to see. These models will be helpful when studying protists and fungi in Unit 6.

**Answers**

**FIGURE 7–14** Prokaryotic cells have a cell membrane, DNA (though not enclosed in a nucleus), and ribosomes in common with animal cells. Prokaryotic cells have a cell membrane, cell wall, DNA (though not in a nucleus), and ribosomes in common with plant cells.

**Biology In-Depth**

**THE ORIGIN OF EUKARYOTES**

The idea that chloroplasts and mitochondria originated in symbiotic relationships with prokaryotic cells is called the endosymbiotic hypothesis. According to this hypothesis, chloroplasts may have originated when cyanobacteria became established in larger prokaryotes, either as parasites or as prey that were not digested. Mitochondria may have been anaerobic heterotrophs that found a safe existence inside larger prokaryotes as oxygen became more abundant in the atmosphere. Over time, host and symbionts became more and more interdependent, and the organisms merged to become a single eukaryotic cell. The endosymbiotic hypothesis is covered in Chapter 19.
### Build Study Skills

Call students’ attention to the table, which summarizes the structures and functions of cells and can help students distinguish between prokaryotes and eukaryotes. Discuss how the table is set up into columns, rows, and cells. Ask what a checkmark in the table means. *(The structure is present in a cell.)* Ask what an empty box indicates. *(The structure is not present in a cell.)* Finally, make sure students know that there are other eukaryotes (fungi and “protists”) besides animals and plants, though for simplicity, only those are listed in this table.

### DIFFERENTIATED INSTRUCTION

#### L1 Struggling Students
Write cell functions on individual index cards. Then, have students select a card and name the cell part or organelle and the kind of cell it is found in. For example, Traps sunlight: chloroplast, plant cell.

#### ELL Focus on ELL: Access Content

#### ADVANCED AND ADVANCED HIGH SPEAKERS
Have students use Figure 7–14 and Lesson 7.2 to complete a Jigsaw Review. Form groups of five. Tell students this is their “learning circle.” Assign each student a number from 1 to 5 within each group. Then, form “study groups” by having students with the same number (all the 2s, all the 5s, and so on) come together. Assign each study group a cell characteristic from the table. (See the left-most column of the table—Cellular Control Center, and so on.) Tell students they will have 10 minutes to use the information in the figure and text to create a presentation on their assigned characteristic. Finally, have students return to their learning circles. Each student in the learning circle should present his or her assigned characteristic to the rest of the group.

### Check for Understanding

#### INDEX CARD SUMMARY
Provide students with an index card on which is written two structures from the cells depicted in Figure 7–14. Ask students to write a sentence that describes how the structures are related to each other.

#### ADJUST INSTRUCTION
If students have difficulty relating structures, have pairs use the table in Figure 7–14 to discuss how their different structures might be related. Then, have students exchange cards and write new sentences that show the relationship between the listed structures.

---

### Cell Structure and Function

<table>
<thead>
<tr>
<th>Structure</th>
<th>Function</th>
<th>Prokaryote</th>
<th>Eukaryote: Animal</th>
<th>Eukaryote: Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cellular Control Center</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nucleus</td>
<td>Contains DNA</td>
<td>Prokaryote DNA is found in cytoplasm.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Organelles That Store, Clean-Up, and Support</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuoles and vesicles</td>
<td>Store materials</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>lysosomes</td>
<td>Break down and recycle macromolecules</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cytoskeleton</td>
<td>Maintains cell shape; moves cell parts; helps cells move</td>
<td>Prokaryotic cells have protein filaments similar to actin and tubulin.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Centrioles</td>
<td>Organize cell division</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Organelles That Build Proteins</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ribosomes</td>
<td>Synthesize proteins</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Endoplasmic reticulum</td>
<td>Assembles proteins and lipids</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Golgi apparatus</td>
<td>Modifies, sorts, and packages proteins and lipids for storage or transport out of the cell</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Organelles That Capture and Release Energy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroplasts</td>
<td>Convert solar energy to chemical energy stored in food</td>
<td>In some prokaryotic cells, photosynthesis occurs in association with internal photosynthetic membranes.</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Mitochondria</td>
<td>Convert chemical energy in food to usable compounds</td>
<td>Prokaryotes carry out these reactions in the cytoplasm rather than in specialized organelles.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Cellular Boundaries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell wall</td>
<td>Shapes, supports, and protects the cell</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Cell membrane</td>
<td>Regulates materials entering and leaving cell; protects and supports cell</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Getting Started

Objectives
7.3.1 Describe passive transport.
7.3.2 Describe active transport.

Student Resources
Study Workbooks A and B, 7.3 Worksheets
Spanish Study Workbook, 7.3 Worksheets

For corresponding lesson in the Foundation Edition, see pages 176–180.

Activate Prior Knowledge
Have students read the analogy of the cell as a nation in Think About It and discuss ways materials might enter and leave a country. Then, ask students to predict how materials might enter or leave a cell.

Remind students what they already know about the cell membrane, and suggest they skim the first four pages of this lesson. Ask what characteristic of a cell membrane might have contributed to Michelle’s problem. (its permeability to water) The difference in salt concentration inside and outside the red blood cells caused excessive water to enter the cells. Students can go online to Biology.com to collect evidence.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES
III, IV, V

CONTENT
C.1.a, C.1.b

INQUIRY
A.2.a

Cell Transport

Passive Transport
What is passive transport?

Cellular cytoplasm consists of many different substances dissolved in water. In any solution, solute particles move constantly. They collide with one another and tend to spread out randomly. As a result, the particles tend to move from an area where they are more concentrated to an area where they are less concentrated. When you add sugar to coffee or tea, for example, the sugar molecules move away from their original positions in the sugar crystals and disperse throughout the hot liquid. The process by which particles move from an area of high concentration to an area of lower concentration is known as diffusion (dih fyou zhun). Diffusion is the driving force behind the movement of many substances across the cell membrane.

Diffusion
Cellular cytoplasm consists of many different substances dissolved in water. In any solution, solute particles move constantly. They collide with one another and tend to spread out randomly. As a result, the particles tend to move from an area where they are more concentrated to an area where they are less concentrated. When you add sugar to coffee or tea, for example, the sugar molecules move away from their original positions in the sugar crystals and disperse throughout the hot liquid. The process by which particles move from an area of high concentration to an area of lower concentration is known as diffusion (dih fyou zhun). Diffusion is the driving force behind the movement of many substances across the cell membrane.

THINK ABOUT IT
In the previous lesson, cell walls and cell membranes were compared to the roof and walls of a factory. When you think about how cells move materials in and out, it can be helpful to think of a cell as a nation. Before you can learn anything about a nation, it’s important to understand where it begins and where it ends. The boundaries of a nation are its borders, and nearly every country tries to regulate and control the goods that move across those borders, like the shipping containers seen here entering and leaving the port of Seattle. Each cell has its own border, which separates the cell from its surroundings and also determines what comes in and what goes out. How can a cell separate itself from its environment and still allow material to enter and leave? That’s where transport across its border, the cell membrane, comes in.

Passive Transport

Every living cell exists in a liquid environment. One of the most important functions of the cell membrane is to keep the cell’s internal conditions relatively constant. It does this by regulating the movement of molecules from one side of the membrane to the other.

Diffusion Cellular cytoplasm consists of many different substances dissolved in water. In any solution, solute particles move constantly. They collide with one another and tend to spread out randomly. As a result, the particles tend to move from an area where they are more concentrated to an area where they are less concentrated. When you add sugar to coffee or tea, for example, the sugar molecules move away from their original positions in the sugar crystals and disperse throughout the hot liquid. The process by which particles move from an area of high concentration to an area of lower concentration is known as diffusion (dih fyou zhun). Diffusion is the driving force behind the movement of many substances across the cell membrane.

Teach for Understanding

ENDURING UNDERSTANDING A cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive.

GUIDING QUESTION How does a cell transport materials across the cell membrane?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how a cell transports materials across the cell membrane. Have students work in small groups to construct analogies that describe how materials move into and out of cells across cell membranes. The analogies can be illustrated.
What does diffusion have to do with the cell membrane? Suppose a substance is present in unequal concentrations on either side of a cell membrane, as shown in Figure 7–15. If the substance can cross the cell membrane, its particles will tend to move toward the area where it is less concentrated until it is evenly distributed. Once the concentration of the substance on both sides of the cell membrane is the same, equilibrium is reached.

Even when equilibrium is reached, particles of a solution continue to move across the membrane in both directions. However, because almost equal numbers of particles move in each direction, there is no further net change in the concentration on either side.

Diffusion depends on random particle movements. Therefore, substances diffuse across membranes without requiring the cell to use additional energy. The movement of materials across the cell membrane without using cellular energy is called passive transport.

In Your Notebook

Explain how you can demonstrate diffusion by spraying air freshener in a large room.

Facilitated Diffusion

Since cell membranes are built around lipid bilayers, the molecules that pass through them most easily are small and uncharged. These properties allow them to dissolve in the membrane’s lipid environment. But many ions, like Cl⁻, and large molecules, like the sugar glucose, seem to pass through cell membranes much more quickly than they should. It’s almost as if they have a shortcut across the membrane.

How does this happen? Proteins in the cell membrane act as carriers, or channels, making it easy for certain molecules to cross. Red blood cells, for example, have protein carriers that allow glucose to pass through them in either direction. Only glucose can pass through these protein carriers. These cell membrane channels facilitate, or help, the diffusion of glucose across the membrane. This process, in which molecules that cannot directly diffuse across the membrane pass through special protein channels, is known as facilitated diffusion. Hundreds of different proteins have been found that allow particular substances to cross cell membranes. Although facilitated diffusion is fast and specific, it is still diffusion, so it does not require any additional use of the cell’s energy.

In Your Notebook

Explain how you can demonstrate diffusion by spraying air freshener in a large room.

Teach

Use Visuals

Explain to students that some materials, such as oxygen, diffuse across the cell membrane, without using energy, while others require energy to pass through. Draw attention to Figure 7–15, and explain that it illustrates one type of passive transport: diffusion directly through the cell membrane.

Ask How do the first and second drawings differ? (The first shows a higher concentration of a solute outside than inside a cell. The second shows a greater number of molecules moving in than moving out, as indicated by more arrows pointing in than out.)

Ask How do you know equilibrium has been reached in the third illustration? (There are equal numbers of molecules on both sides of the membrane, and the arrows show about the same number of molecules moving in and moving out.)

Emphasize that equilibrium does not mean that movement stops; rather it continues in both directions, and the same concentration is maintained on both sides of the membrane.

DIFFERENTIATED INSTRUCTION

ELL English Language Learners Explain to English learners that concentration has multiple meanings in English. Reassure students who are already familiar with the definition of concentration as “directed effort or attention” that this is one correct definition. Then, point out concentration has a specific meaning in science. The scientific meaning of concentration refers to the relative amount of one substance in another, for example, the concentration of salt in water.

LPR Less Proficient Readers If students have trouble answering the caption question, rephrase it to read: What would be different if the high concentration had been inside the cell to start with?

Biology In-Depth

RATE OF FACILITATED DIFFUSION

In simple diffusion, concentration is the only factor that affects rate. In facilitated diffusion, the rate also depends upon the number of specific carrier protein molecules in the membrane, because the diffusing molecules can move across the membrane only through those proteins. An example is the diffusion of glucose into cells. Such diffusion occurs most of the time as facilitated diffusion. No matter how much the cell “needs” glucose or how great the difference in concentration is between the inside and outside of the cell, the rate at which the glucose can diffuse into the cell has a limit because of the limited number of glucose carrier protein molecules in the lipid bilayer.

Answers

FIGURE 7–15 If the concentration of solute particles had been higher on the inside of the cell, more solute particles would have moved out of the cell than into the cell.

IN YOUR NOTEBOOK Students’ answers should reflect an understanding that in diffusion, molecules move randomly from an area where they are more concentrated to areas where they are less concentrated. So, when air freshener is sprayed in a room, the smell will diffuse from its point of origin until it can be detected everywhere.
Teach continued

Use Visuals

Use Figure 7–17 to introduce osmosis.

Ask What happens to the concentrations on each side of the membrane as water diffuses through? (The concentrations change until they reach equilibrium.) Why does the water level rise in the right side of the tube and drop in the left side? (The net movement of water molecules is to the right side, because initially the concentration of water is lower there. The movement of water molecules across the barrier changes the water level on both sides of the tube.)

Ask volunteers to explain what the white arrows in part B of the figure represent. (movement of water molecules through aquaporins)

DIFFERENTIATED INSTRUCTION

ELL Struggling Students Immerse a tea bag in a beaker of hot water. Tell students the bag represents a cell membrane. Ask how they know something is passing through the bag. (The water turns color.) Ask if there is anything that cannot pass through the bag. (tea leaves) Relate this to Figure 7–17 (water molecules can move through the barrier, but sugar molecules cannot).

ELL Focus on ELL: Extend Language

ALL SPEAKERS Have students use the Think-Pair-Share strategy to discuss the word osmosis. Pair beginning speakers with advanced speakers of the same language. Have students read and discuss the information about osmosis. Encourage advanced speakers to explain the concepts in their native language.

Study Wkbks A/B, Appendix S14, Think-Pair-Share.

Osmosis is a form of diffusion. It does not require energy.

Answers

FIGURE 7–17 Osmosis is a form of diffusion. It does not require energy.

Biology In-Depth

AQUAPORINS

Osmosis is easily observed in cells, yet for a long time, it was a mystery as to how water could cross cell membranes so quickly. Water is a polar molecule and is not soluble in lipids. Water would not be expected to cross a membrane made up of a lipid bilayer. In 1990, Peter Agre discovered channels through which water molecules can cross cell membranes. The channels, called aquaporins, are proteins that span the depth of the membrane. Polar water molecules are able to move through channels because of how they relate to charges within the proteins. Aquaporins have been found in prokaryotic and eukaryotic cells. Eleven different types of aquaporins have been found in humans. One type plays an active role in water balance in the kidneys. Some aquaporins in plants appear to close in response to stress. For his discovery, Peter Agre received the Nobel Prize in Chemistry in 2003.
Hypertonic, isotonic, and hypotonic are terms used to describe the concentration of solutes (molecules that dissolve in water) in relation to the cell. Aquaporins are specific protein channels in the cell membrane that facilitate the diffusion of water.

Osmosis is the net movement of water molecules across a semipermeable membrane from an area of lower solute concentration to an area of higher solute concentration. This movement is driven by differences in solute concentration and is a process of facilitated diffusion, not requiring energy.

**Isotonic** solutions have the same solute concentration as the cell, so there is no net movement of water. **Hypertonic** solutions have a higher solute concentration than the cell, causing water to move out of the cell, shrinking it. **Hypotonic** solutions have a lower solute concentration than the cell, causing water to move into the cell, swelling it.

In Your Notebook

In your own words, explain why osmosis is really just a special case of facilitated diffusion.

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**Check for Understanding**

**ONE-MINUTE RESPONSE**

Present students with a drawing of a blood cell, and tell them the cell is in fresh water. Have students draw an arrow showing the direction in which water will move. Finally, ask them to write a sentence defending their choice of direction, using the appropriate term or terms—isotonic, hypotonic, or hypertonic. (Responses should show the arrow going into the cell. Sample sentence: Fresh water is hypotonic to the inside of the cell, so the water will diffuse into the cell.)

**ADJUST INSTRUCTION**

If responses show that students do not understand the effect of solute concentration on the direction of the flow of water in a cell, have them review the table in Figure 7–18 and adjust their answer accordingly.

**Connect to the Real World**

Relate the illustrations in the bottom row of Figure 7–18 to what happens when a lawn care company sprays a fertilizer-water mixture onto grass. Point out that if too much fertilizer and too little water are sprayed on grass, the grass may die and the lawn may turn brown.

**Ask** Would the grass cells have gained or lost water? (lost water)

**Ask** Which plant cell in Figure 7–18 shows what would happen to the grass at the cellular level? (the plant cell in the middle column, which shows water going out)

**Ask** Was the fertilizer-water mixture hypotonic or hypertonic compared to the cytoplasm in the grass cells? (The fertilizer-water mixture was hypertonic compared to the cytoplasm in the grass cells.)

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** Some students may be confused by the two-headed arrow in Figure 7–18, which depicts an isotonic condition. Explain that the arrow with two heads means that water is moving both into and out of the cell at the same time. Suggest that it is similar to people streaming out one door at a movie theater as others stream in through another door.
Connect to Physics

Before students read about active transport, help them to understand and compare the role of energy in moving materials. Have small groups set up ramps using a board and books. Ask them to roll a ball down the ramp and describe how easy or difficult it is to do. Then, have them push the ball back up the ramp using a pencil. Ask which process required energy to accomplish. Have students suggest ways to move the ball back up the ramp more easily. Ask what processes they think a cell might have evolved to make the process of moving materials more efficient.

DIFFERENTIATED INSTRUCTION

Special Needs Use an analogy of going into a building through an open door or going in through a revolving door to illustrate active transport. Ask how an open door is like a carrier protein in facilitated diffusion. (It is easy to walk through and requires no extra energy.) Ask how moving through a revolving door is like active transport. (A person has to use energy to push the door and move through the doorway in a small compartment.)

VISUAL SUMMARY

Use Figure 7–19 to explain that energy is needed to get certain substances into or out of a cell, because the cell membrane is selective. For substances that cannot pass through the membrane freely, active transport is used, and it requires energy. Draw students’ attention to the annotation about protein pumps. Tell them that the change from ATP to ADP represents the use of energy by a cell.

Art in Motion: Active Transport dynamically explores protein pumps, endocytosis, and exocytosis.

Active Transport

What is active transport?

As powerful as diffusion is, cells sometimes must move materials against a concentration difference. The movement of materials against a concentration difference is known as active transport. Active transport requires energy. The active transport of small molecules or ions across a cell membrane is generally carried out by transport proteins—protein pumps—that are found in the membrane itself. Larger molecules and clumps of material can also be actively transported across the cell membrane by processes known as endocytosis and exocytosis. The transport of these larger materials sometimes involves changes in the shape of the cell membrane. The major types of active transport are shown in Figure 7–19.

Molecular Transport Small molecules and ions are carried across membranes by proteins in the membrane that act like pumps. Many cells use protein pumps to move calcium, potassium, and sodium ions across cell membranes. Changes in protein shape seem to play an important role in the pumping process. A considerable portion of the energy used by cells in their daily activities is spent providing the energy to keep this form of active transport working. The use of energy in these systems enables cells to concentrate substances in a particular location, even when the forces of diffusion might tend to move these substances in the opposite direction.

Quick Facts

PROTEIN MOLECULES AND ACTIVE TRANSPORT

One of the most important examples of active transport is the sodium-potassium pump, in which sodium ions are maintained at a lower concentration inside a cell than outside, and potassium ions are maintained at a higher concentration inside the cell than outside. The active transport of these ions by protein molecules is vital to the production of electrochemical impulses along nerve cells. At one time, scientists thought the protein molecules rotated as they transported substances through the cell membrane, picking up molecules on the outside, rotating, and then dumping them into the cell. Now, scientists think the transported molecules are squeezed through the transport proteins, because it has been observed that the proteins change their configuration to accommodate the incoming molecules.
**Lead a Discussion**

Have students discuss why endocytosis is an example of active transport and not facilitated diffusion. (Endocytosis requires energy to engulf a particle and form a vesicle around it.)

**DIFFERENTIATED INSTRUCTION**

- **Struggling Students**
  - To help students understand endocytosis, use clay to model a macrophage engulfing a bacterium.

**Assess and RemEDIATE**

**EVALUATE UNDERSTANDING**

Ask students to write a paragraph distinguishing active transport from diffusion. Then, have them complete the 7.3 Assessment.

**REMEDIATION SUGGESTION**

- **Struggling Students**
  - If students have trouble answering Question 2a, have them use a Venn Diagram to compare the two processes.

**Study Wkbs A/B**, Appendix S33, Venn Diagram. Transparencies, GO18.

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**Lesson 7.3**

**Assessment Answers**

1a. Particles move from a more to a less concentrated area.

1b. Water diffuses across a selectively permeable membrane from a more to a less concentrated area.

1c. Diffusion occurs when molecules spread out by moving randomly. Facilitated diffusion occurs when protein channels help molecules move across the cell membrane.

2a. Active transport uses energy to move materials across a cell membrane against a concentration gradient. Passive transport moves materials across a cell membrane in the direction of a concentration gradient, without using energy.

2b. In molecular transport, energy is used by protein pumps to carry small molecules across the cell membrane. In bulk transport, vesicles or vacuoles are used to move large molecules across the cell membrane.

2c. In endocytosis, a vesicle forms from an infolding of the cell membrane, surrounds large molecules entering the cell, and breaks off into the cytoplasm. In exocytosis, a vesicle fuses with the cell membrane and forces the material to be expelled out of the cell.

**BUILD VOCABULARY**

3. Sample answers: *iso* means “same”; *hyper* means “over”; *hypo* means “under”; *isometric*, *hyperbole*, *hypodermic*

4. The word part -*cytosis* refers to cells. Phagocytosis is the engulfing of foreign particles. Pinocytosis is the ingestion of fluid.
Lesson 7.4 • Lesson Overview • Lesson Notes

LESSON 7.4

Getting Started

Objectives

7.4.1 Explain how unicellular organisms maintain homeostasis.
7.4.2 Explain how multicellular organisms maintain homeostasis.

Student Resources

Study Workbooks A and B, 7.4 Worksheets
Spanish Study Workbook, 7.4 Worksheets
Lab Manual B, 7.4 Data Analysis Worksheet

Build Background

Ask students how often during the day they encounter single-celled organisms. Many students may not realize that they come in contact with millions of bacteria every time they brush their teeth, eat a piece of fruit, touch a doorknob, or take a breath of air. Ask students why these organisms are so successful. Ask what these organisms need to stay alive. (water, energy) Introduce the term homeostasis. Tie the discussion to what students have already learned about cell organelles and their specific functions by asking how a single cell can stay in balance in its environment.

UNIFYING CONCEPTS AND PROCESSES

I, III, IV, V

CONTENT

C.1.a, C.1.d, C.1.f, C.5.d

INQUIRY

A.1.c, A.1.d, A.2.a

Homeostasis and Cells

Key Questions

How do individual cells maintain homeostasis?
How do the cells of multicellular organisms work together to maintain homeostasis?

THINK ABOUT IT

From its simple beginnings, life has spread to every corner of our planet, penetrating deep into the earth and far beneath the surface of the seas. The diversity of life is so great that you might have to remind yourself that all living things are composed of cells, have the same basic chemical makeup, and even contain the same kinds of organelles. This does not mean that all living things are the same: Differences arise from the ways in which cells are specialized and the ways in which cells associate with one another to form multicellular organisms.

The Cell as an Organism

How do individual cells maintain homeostasis?

Cells are the basic living units of all organisms, but sometimes a single cell is the organism. In fact, in terms of their numbers, unicellular organisms dominate life on Earth. A single-celled organism does everything you would expect a living thing to do. Just like other living things, unicellular organisms must maintain homeostasis, relatively constant internal physical and chemical conditions. To maintain homeostasis, unicellular organisms grow, respond to the environment, transform energy, and reproduce.

Unicellular organisms include both prokaryotes and eukaryotes. Prokaryotes, especially bacteria, are remarkably adaptable. Bacteria live almost everywhere—in the soil, on leaves, in the ocean, in the air, even within the human body.

Many eukaryotes, like the protozoan in Figure 7–21, also spend their lives as single cells. Some types of algae, which contain chloroplasts and are found in oceans, lakes, and streams around the world, are single celled. Yeasts, or unicellular fungi, are also widespread. Yeasts play an important role in breaking down complex nutrients, making them available for other organisms. People use yeasts to make bread and other foods.

Don’t make the mistake of thinking that single-celled organisms are always simple. Prokaryote or eukaryote, homeostasis is still an issue for each unicellular organism. That tiny cell in a pond or on the surface of your pencil still needs to find sources of energy or food, to keep concentrations of water and minerals within certain levels, and to respond quickly to changes in its environment. The microscopic world around us is filled with unicellular organisms that are successfully maintaining that homeostatic balance.

FIGURE 7–21 Unicellular Life

Single-celled organisms, like this freshwater protozoan, must be able to carry out all of the functions necessary for life (pig. 600x).

Teach for Understanding

ENDURING UNDERSTANDING A cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive.

GUIDING QUESTION How does a cell maintain homeostasis both within itself and as part of a multicellular organism?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how a cell maintains homeostasis.

Have small groups of students write a script consisting of a series of creative, content-based questions that might be used to interview a cell about maintaining homeostasis. The script should supply answers to the questions.
Multicellular Life

How do the cells of multicellular organisms work together to maintain homeostasis?

Unlike most unicellular organisms, the cells of human beings and other multicellular organisms do not live on their own. They are interdependent; and like the members of a winning baseball team, they work together. In baseball, each player plays a particular position: pitcher, catcher, infielder, outfielder. And to play the game effectively, players and coaches communicate with one another, sending and receiving signals. Cells in a multicellular organism work the same way. The cells of multicellular organisms become specialized for particular tasks and communicate with one another to maintain homeostasis.

Cell Specialization The cells of a multicellular organism are specialized, with different cell types playing different roles. Some cells are specialized to move; others, to react to the environment; still others, to produce substances that the organism needs. No matter what its role, each specialized cell, like the ones in Figures 7–22 and 7–23, contributes to homeostasis in the organism.

In Your Notebook Where in the human body do you think you would find cells that are specialized to produce digestive enzymes? Why?

FIGURE 7–22 Specialized Animal Cells: Human Trachea Epithelium

▶ Specialized Animal Cells Even the cleanest, freshest air is dirty, containing particles of dust, smoke, and bacteria. What keeps this stuff from getting into your lungs? That’s the job of millions of cells that work like street sweepers. These cells line the upper air passages. As you breathe, they work night and day sweeping mucus, debris, and bacteria out of your lungs. These cells are filled with mitochondria, which produce a steady supply of the ATP that powers the cilia on their upper surfaces to keep your lungs clean.

FIGURE 7–23 Specialized Plant Cells: Pine Pollen

▶ Specialized Plant Cells How can a pine tree, literally rooted in place, produce offspring with another tree hundreds of meters away? It releases pollen grains, some of the world’s most specialized cells. Pollen grains are tiny and light, despite tough walls to protect the cells inside. In addition, pine pollen grains have two tiny wings that enable them to float in the slightest breeze. Pine trees release millions of pollen grains like these to scatter in the wind, land on seed cones, and begin the essential work of starting a new generation.

Quick Facts

THE BASIC TYPES OF TISSUES

A tissue is a group of specialized cells that have a common structure and a common function. In most instances, all the cells in a tissue look alike. Despite the great diversity of animals that have evolved, there are only four basic types of animal tissues: epithelial, connective, muscle, and nervous tissues. Epithelial tissue consists of tightly packed cells, which line the cavities inside the body and cover the outside of the body. A primary function of epithelial tissue is protection against injury, invaders, and fluid loss. Connective tissue connects and supports other tissues. It includes fat, bone, cartilage, blood, and fibrous strands such as tendons and ligaments. Muscle tissue consists of long cells that contract. It is the most abundant tissue in most animals. Nervous tissue includes cells that sense stimuli and transmit signals from one part of the body to another.

BUILD Vocabulary

PREFIXES The prefix homeo- in homeostasis means “the same.” Organisms are constantly trying to maintain homeostasis. To keep their internal physical and chemical conditions relatively constant despite changes in their internal and external environments.

Teach

Lead a Discussion

Use the analogy of a baseball team to introduce the idea that multicellular organisms are made up of many different kinds of cells, each specialized for different functions. Ask students to suggest specializations a multicellular organism needs to maintain homeostasis. List these suggestions on the board. Then, focus students’ attention on Figures 7–22 and 7–23. Ask how each kind of cell is specialized for the role it plays. (A trachea epithelium cell has cilia that clear debris; a pine pollen cell is tiny, lightweight, and floats in air.)

DIFFERENTIATED INSTRUCTION

Special Needs Some students might have difficulty finding the main idea on the page. Have them read aloud the paragraph under the subheading, Cell Specialization. Ask them to state three ways that cells are specialized. (Some cells move, some react to the environment, and others produce substances the organism needs.) Extend this by having students look at Figures 7–22 and 7–23 and identifying what makes these cells specialized.

Answers

IN YOUR NOTEBOOK Sample answer: in the digestive system, because enzymes are needed to break down food.
Mitochondria Distribution in the Mouse

Scientists studied the composition of several organs in the mouse. They found that some organs and tissues contain more mitochondria than others. They described the amount of mitochondria present as a percentage of total cell volume. The higher the percentage volume made up of mitochondria, the more mitochondria present in the cells of the organ. The data are shown in the graph.

1. **Interpret Graphs** What approximate percentage of cell volume in the mouse liver is composed of mitochondria?

2. **Calculate** Approximately how much more cellular volume is composed of mitochondria in the left ventricle than in the pituitary gland?

3. **Infer** There are four chambers in the mouse heart, the right and left ventricles, and the right and left atria. Based on the data given, which chamber, the left ventricle or left atrium, do you think pumps blood from the heart to the rest of the body? Explain your answer.

**Levels of Organization**

The specialized cells of multicellular organisms are organized into tissues, then into organs, and finally into organ systems, as shown in Figure 7–24. A tissue is a group of similar cells that performs a particular function. Many tasks in the body are too complicated to be carried out by just one type of tissue. In these cases, many groups of tissues work together as an organ. For example, each muscle in your body is an individual organ. Within a muscle, however, there is much more than muscle tissue. There are nervous tissues and connective tissues too. Each type of tissue performs an essential task to help the organ function. In most cases, an organ completes a series of specialized tasks. A group of organs that work together to perform a specific function is called an organ system. For example, the stomach, pancreas, and intestines work together as the digestive system.

**Mitochondria Distribution**

<table>
<thead>
<tr>
<th>Organ</th>
<th>Mitochondria Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart, left ventricle</td>
<td><img src="" alt="Graph" /></td>
</tr>
<tr>
<td>Heart, left atrium</td>
<td><img src="" alt="Graph" /></td>
</tr>
<tr>
<td>Liver</td>
<td><img src="" alt="Graph" /></td>
</tr>
<tr>
<td>Pituitary gland</td>
<td><img src="" alt="Graph" /></td>
</tr>
</tbody>
</table>

**ANALYZING DATA**

**PURPOSE** Students will interpret data to determine the percentage of cell volume taken up by mitochondria in three different mouse organs and suggest the effect that a higher percentage of mitochondria might have on an organ’s function.

**PLANNING** Remind students that bar graphs commonly are used in order to show comparisons.

**ANSWERS**

1. about 18 percent

2. About 40 percent more cellular volume is composed of mitochondria in the left ventricle. (49% - 9% = 40%)

3. The left ventricle pumps blood from the heart to the rest of the body. It has more mitochondria per cellular volume than the left atrium. Therefore, it probably pumps with more force.
The organization of the body’s cells into tissues, organs, and organ systems creates a division of labor among those cells that allows the organism to maintain homeostasis. Specialization and interdependence are two of the remarkable attributes of living things. Appreciating these characteristics is an important step in understanding the nature of living things.

**Cellular Communication**

Cells in a large organism communicate by means of chemical signals that are passed from one cell to another. These cellular signals can speed up or slow down the activities of the cells that receive them and can even cause a cell to change what it is doing in a most dramatic way. Certain cells, including those in the heart and liver, form connections, or cellular junctions, to neighboring cells. Some of these junctions, like those in Figure 7–25, hold cells together firmly. Others allow small molecules carrying chemical messages or signals to pass directly from one cell to the next. To respond to one of these chemical signals, a cell must have a receptor to which the signaling molecule can bind. Some receptors are on the cell membrane; receptors for other types of signals are inside the cytoplasm. The chemical signals sent by various types of cells can cause important changes in cellular activity. For example, the electrical signal that causes heart muscle cells to contract begins in a region of the muscle known as the pacemaker. Ions carry that electrical signal from cell to cell through a special connection known as a gap junction, enabling millions of heart muscle cells to contract as one in a single heartbeat. Other junctions hold the cells together, so the force of contraction does not tear the muscle tissue. Both types of junctions are essential for the heart to pump blood effectively.

**Assessment Answers**

1a. Homeostasis is the maintenance of relatively stable internal physical and chemical conditions by an organism.

1b. They maintain homeostasis by growing, responding to changes in their environment, transforming energy, and reproducing.

1c. The contractile vacuole helps maintain water balance in paramecia by expelling excess water that would otherwise accumulate and burst the cell.

2a. Cellular specialization describes how, in multicellular organisms, groups of cells play different, specific roles.

2b. Cellular junctions help organisms maintain homeostasis by connecting cells to their neighbors, thus enabling communication between cells. Receptors allow cells to respond to chemical messages.

2c. Answers may vary. Predictions should note that muscle cells need energy to move and, therefore, probably contain a large number of mitochondria.

3. Sample answer: The members of a basketball team are like specialized cells, because different members play different roles. For example, the point guard calls the plays and the center shoots the ball. The whole team is like a body system, because team members work together to try to win the game.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Detecting Diffusion described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Students should wear goggles, disposable gloves, and aprons. Caution them to handle solutions containing iodine with care. Make sure they wash their hands thoroughly after the lab.

Pre-Lab: Detecting Diffusion

Problem How can you determine whether solutes are diffusing across a membrane?

Materials dialysis tubing, scissors, metric ruler, 250 mL beakers, twist ties, 10-mL graduated cylinders, 1% starch solution, iodine solution, forceps, 15% glucose solution, glucose test strip

Lab Manual Chapter 7 Lab

Skills Focus Use Models, Infer, Compare and Contrast

Connect to the Big idea The cell membrane forms a thin flexible barrier between a cell and its surroundings. The cell membrane controls what enters the cell and what leaves the cell. Diffusion is the process responsible for much of the movement across a cell membrane. During diffusion, solutes move from an area of high concentration to an area of lower concentration. When water is the molecule that is diffusing, the process is called osmosis. Proteins embedded in the membrane can facilitate the diffusion of many particles, including water. In this lab, you will use dialysis tubing to model the diffusion of small molecules.

Background Questions

a. Review What does it mean to say that a membrane is selectively permeable?

b. Explain Does the movement of molecules stop when the concentration of a solute is equal on both sides of a membrane? Explain.

c. Compare and Contrast What is the main difference between passive transport and active transport?

Pre-Lab Questions

1. Draw Conclusions How will you tell whether starch has diffused across the membrane in Part A? How will you tell whether iodine has diffused across the membrane?

2. Draw Conclusions How will you be able to tell whether glucose has diffused across the membrane in Part B?

3. Use Analogies How is a window screen similar to a cell membrane?

Pre-Lab Answers

Background Questions

a. Some substances can pass through the membrane while other substances cannot pass through the membrane.

b. The movement does not stop, but an equal number of molecules move in each direction to maintain equilibrium.

c. The movement of substances through passive transport does not require energy; the movement of substances through active transport requires energy.

Pre-Lab Questions

1. If the solution outside the tubing turns blue black, then starch diffused out of the tubing. If the solution inside the tubing turns blue black, then iodine diffused into the tubing.

2. A glucose test strip will change color in the presence of glucose.

3. Sample answer: Like a cell membrane, a window screen prevents the passage of some things, such as insects, while allowing other things, such as air, to flow in and out of a house.
Study Guide

7.1 Life Is Cellular

The cell theory states that (1) all living things are made up of cells, (2) cells are the basic units of structure and function in living things, and (3) new cells are produced from existing cells.

Most microscopes use lenses to magnify the image of an object by focusing light or electrons.

Prokaryotic cells do not separate their genetic material with a nucleus. In eukaryotic cells, the nucleus separates the genetic material from the rest of the cell.

The nucleus contains nearly all the cell’s DNA and, with it, the coded instructions for making proteins and other important molecules.

Vacuoles store materials like water, salts, proteins, and carbohydrates. Lysosomes break down large molecules into smaller ones that can be used by the cell. They are also involved in breaking down organelles that have outlived their usefulness. The cytoskeleton helps the cell maintain its shape and is also involved in movement.

Proteins are assembled on ribosomes.

Proteins made on the rough ER include those that will be released from the cell as well as many membrane proteins and proteins destined for specialized locations within the cell. The Golgi apparatus then modifies, sorts, and packages proteins and other materials for storage in the cell or release outside the cell.

Chloroplasts capture the energy from sunlight and convert it into food that contains chemical energy. Mitochondria use the chemical energy stored in food into compounds that are more convenient for the cell to use.

The cell membrane regulates what enters and leaves the cell and also protects and supports the cell.

7.2 Cell Structure

Cell [191] | Nucleus [193]
---|---
Cell theory [191] | Eukaryote [193]
Cell membrane [193] | Prokaryote [193]

7.3 Cell Transport

Passive transport (including diffusion and osmosis) is the movement of materials across the cell membrane without cellular energy.

The movement of materials across a concentration difference is known as active transport. Active transport requires energy.

7.4 Homeostasis and Cells

To maintain homeostasis, unicellular organisms grow, respond to the environment, transform energy, and reproduce.

The cells of multicellular organisms become specialized for particular tasks and communicate with one another to maintain homeostasis.

Homeostasis [214] | Organ system [216]
---|---
Tissue [216] | Receptor [217]
Organ [216]

Think Visually

Use the terms diffusion, facilitated diffusion, osmosis, active transport, endocytosis, phagocytosis, pinocytosis, and exocytosis to create a concept map about the ways substances can move into and out of cells.

Study Online

Editable Worksheets

Pages of Study Workbooks A and B, Lab Manuals A and B, and the Assessment Resources Book are available online. These documents can be easily edited using a word-processing program.

Lesson Overview

Have students reread the Lesson Overviews to help them study chapter concepts.

Vocabulary Review

The Flash Cards and Match It provide an interactive way to review chapter vocabulary.

Chapter Assessment

Have students take an online version of the Chapter 7 Assessment.

Standardized Test Prep

Students can take an online version of the Standardized Test Prep. You will receive their scores along with ideas for remediation.

Diagnostic and Benchmark Tests

Use these tests to monitor your students’ progress and supply remediation.

Performance Tasks

SUMMATIVE TASK

Have students imagine they are small enough to live within a one-celled organism. Have them write a seven-day account describing how the cell obtains, manufactures, and/or uses such things as food, proteins, and sufficient water. Students should describe how they got into the cell and how they will leave. Students need to include all of the parts of the cell they have studied and the processes of active and passive transport.

TRANSFER TASK

Have the class plan a series of five newspaper articles that will run in a hypothetical newspaper over a period of five days. Have students decide on five topics that will cover cell structure and function and answer the Essential Question: How are cell structures adapted to their functions? Each group should submit a storyboard showing what the article will say, how it will be illustrated, what its headline will be, and how it will be presented to the class.

Answers

THINK VISUALLY

Answers may vary. Check the accuracy of concept maps. To make certain that students clearly understand the differences among these concepts, suggest they add a caption or small drawing by each term.
Lesson 7.1

UNDERSTAND KEY CONCEPTS
1. d  2. b  3. b
4. Tables can have two columns. Left column head should be Scientist, with rows Hooke, Schleiden, Schwann, and Virchow. Right column head should be Contribution, with rows cork “cells,” plants made of cells, all animals made of cells, existing cells divide to make new cells.

THINK CRITICALLY
5. a light microscope
6. Alike: both have a cell membrane, DNA, and ribosomes; Different: prokaryotic DNA is not found in a nucleus.

Lesson 7.2

UNDERSTAND KEY CONCEPTS
7. c  8. b  9. a
10. Students’ drawings should be similar to the nucleus in Figure 7–7, with nuclear membrane, nuclear pores, nucleolus, and chromatin labeled and their functions identified.
11. Ribosomes assemble proteins according to coded directions from DNA.
12. The Golgi apparatus modifies, sorts, and packages proteins and other materials from the ER for storage or release through the cell membrane.

THINK CRITICALLY
13. Because enzymes are proteins, ribosomes, the endoplasmic reticulum, and the Golgi apparatus would be involved in producing them.

Lesson 7.3

UNDERSTAND KEY CONCEPTS
15. d  16. c
17. In diffusion, particles move randomly from areas of higher concentration to areas of lower concentration until equilibrium is reached. At equilibrium, the concentration is more or less the same throughout.
18. Osmosis is the diffusion of water through a selectively permeable membrane. Only water can move by osmosis.
19. Passive transport acts to equalize concentrations on both sides of the membrane and does not require energy. Active transport requires energy and moves materials against a concentration gradient.
**THINK CRITICALLY**

20. The diffusing salt particles (the sodium and chloride ions that make up salt) and water molecules will eventually reach equilibrium without a change in the fluid on either side.

21. The blood cells would swell and burst, because the concentration of solute is higher inside the cells than in the solution outside. Therefore, the solution outside the cells would tend to diffuse into the cells.

22. Answers may vary. Students might hypothesize that diffusion will take place most rapidly in the beaker with hot water.

**Lesson 7.4**

**UNDERSTAND KEY CONCEPTS**

23. c  24. a

25. In multicellular organisms, each cell has a specialized role to play to maintain homeostasis, so all cells must work together to maintain homeostasis.

26. Groups of similar cells that perform a particular function form tissues. Different types of tissues that perform a specific function work together as an organ. A group of organs that work together for a specific function form an organ system.
THINK CRITICALLY
27. Predictions should say that muscle cells contain more mitochondria. Because muscle cells are responsible for movement, they require more energy than skin cells.
28. If a person needs a pacemaker, his or her heart cells may have lost some of their ability to send chemical messages or to respond to messages.

Connecting Concepts
USE SCIENCE GRAPHICS
29. Prokaryotes: Escherichia coli, Streptococcus pneumoniae
Eukaryotes: human erythrocyte, human ovum, Saccharomyces cerevisiae
30. In general, prokaryotes are much smaller than eukaryotes.
31. Based upon size, Chlamydomonas reinhardtii is likely to be a eukaryote.

WRITE ABOUT SCIENCE
32. Sample answer: Companies that market high-solute drinks should not say that the drinks quench thirst. If you drink something with a high solute concentration, water will move out of the body cells and into the bloodstream. This can actually increase thirst.
33. Active transport is one way in which organisms maintain homeostasis. For example, an amoeba uses phagocytosis to take in food. The amoeba needs the food for energy and growth.

34. Calculate By approximately what percentage is a molecule of carbon dioxide smaller than a molecule of glucose? [Math]
   a. 25%  b. 50%  c. 75%  d. 100%

35. Formulate Hypotheses Which of the following is a logical hypothesis based on the graph shown?
   a. Cells contain more glucose than oxygen.
   b. Oxygen molecules diffuse across the cell membrane faster than water molecules.
   c. Glucose molecules must cross the cell membrane by active transport.
   d. Carbon dioxide crosses the cell membrane faster than glucose.

PURPOSE Students will calculate the relative size of molecules and hypothesize how the size of molecules affects their diffusion.

PLANNING Review how to calculate percent differences. Then, compare specific percent differences with more familiar indicators of difference, e.g., by equating a twofold increase with a 100 percent increase.
### Multiple Choice

1. Animal cells have all of the following EXCEPT
   A mitochondria.
   B chloroplasts.
   C a nucleus.
   D a cell membrane.

2. The nucleus includes all of the following structures EXCEPT
   A cytoplasm.
   B a nuclear envelope.
   C DNA.
   D a nucleolus.

3. The human brain is an example of a(n)
   A cell.
   B tissue.
   C organ.
   D organ system.

4. Which cell structures are sometimes found attached to the endoplasmic reticulum?
   A chloroplasts
   B nuclei
   C mitochondria
   D ribosomes

5. Which process always involves the movement of materials from inside the cell to outside the cell?
   A phagocytosis
   B exocytosis
   C endocytosis
   D osmosis

6. Which of the following is an example of active transport?
   A facilitated diffusion
   B osmosis
   C diffusion
   D endocytosis

7. The difference between prokaryotic and eukaryotic cells involves the presence of
   A a nucleus.
   B genetic material in the form of DNA.
   C chloroplasts.
   D a cell membrane.

Questions 8–10

In an experiment, plant cells were placed in sucrose solutions of varying concentrations, and the rate at which they absorbed sucrose from the solution was measured. The results are shown in the graph below.

![Sucrose Uptake Graph](image)

8. In this experiment, sucrose probably entered the cells by means of
   A endocytosis.
   B osmosis.
   C phagocytosis.
   D active transport.

9. The graph shows that as the concentration of sucrose increased from 10 to 30 mmol/L, the plant cells
   A took in sucrose more slowly.
   B took in sucrose more quickly.
   C failed to take in more sucrose.
   D secreted sucrose more slowly.

10. Based on the graph, the rate of sucrose uptake
    A increased at a constant rate from 0 to 30 mmol/L.
    B decreased at varying rates from 0 to 30 mmol/L.
    C was less at 25 mmol/L than at 5 mmol/L.
    D was constant between 30 and 40 mmol/L.

### Open-Ended Response

11. What would you expect to happen if you placed a typical cell in fresh water?

### Test-Taking Tip

**INTERPRET GRAPHS**

Tell students that when answering a question based on experimental data, they should read the description of the experiment carefully to determine the steps followed. They should also examine the description of the experiment and the labels on the graph axes to determine the independent and dependent variables. Suggest they look for any trends in the data. For example, when studying a graph, they should ask, “If x increases, what happens to y?”

---

A typical cell in fresh water will take in water, swell, and may burst.
Connect to the Big Idea

After students have looked at the micrograph of leaf cells, ask them to identify the green organelles inside the leaf cells. (chloroplasts) Remind students that they learned about chloroplasts in Chapter 7. Then, ask what the function of chloroplasts is. (Chloroplasts capture the energy of sunlight and convert it into chemical energy through the process of photosynthesis.) Have students anticipate the answer to the question, How do plants and other organisms capture energy from the sun?

Finally, help students make a connection between energy from the sun, photosynthesis, and the food we eat. If you have studied ecology in Unit 2, remind students of the concepts of food chains, primary producers, and consumers. Then, ask if the energy we get from eating food is the same energy that plants harness from sunlight.

Have students read over the Chapter Mystery and predict how they think the willow tree gained the extra 75 kilograms in Jan van Helmont’s investigation. Ask them what process occurring at the cellular level in the plant might be connected to its gain in mass. (photosynthesis) Explain that the Chapter Mystery image is a sixteenth-century watering can.

Have students preview the chapter vocabulary using the Flash Cards.

Understanding by Design

In Chapter 8, students learn about the process of photosynthesis and further explore the Enduring Understanding of how a cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive. Clearly, the ability of photosynthetic cells to harness the sun’s energy gives them a special function in the biosphere. The Big Idea, Essential Question, and Guiding Questions shown in the graphic organizer at the right help frame students’ exploration.

PERFORMANCE GOALS

In Chapter 8, students will learn about the organisms and cellular structures involved in photosynthesis as well as the two stages of chemical reactions that make up the process. They explore analogies that help them understand the function of ATP and electron carriers as well as complete an activity in which they observe a byproduct of photosynthesis—oxygen—collecting on the leaves of a water plant.
OUT OF THIN AIR?

One of the earliest clues as to how photosynthesis works came from a simple study of plant growth. When a tiny seed grows into a massive tree, where does all its extra mass come from? More than 300 years ago, a Flemish physician named Jan van Helmont decided to find out. He planted a young willow tree, with a mass of just 2 kilograms, in a pot with 90 kilograms of dry soil. He watered the plant as needed and allowed it to grow in bright sunlight. Five years later, he carefully removed the tree from the pot and weighed it. It had a mass of about 77 kilograms. Where did the extra 75 kilograms come from? The soil, the water—or, maybe, right out of thin air? As you read this chapter, look for clues to help you discover where the willow tree’s extra mass came from. Then, solve the mystery.

Never Stop Exploring Your World.
Understanding Jan van Helmont’s experiments is just the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

What’s Online

Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
The Chapter Mystery explores the question: As a tree grows and gains mass, where does the mass come from?

UNTAMED SCIENCE VIDEO
Students go to Panama with researchers looking into how plants respond to increased levels of CO₂.

VISUAL ANALOGIES
Students use analogies to understand how cells can release energy stored in ATP, and how high-energy electrons can be carried from one place to another in a cell.

INTERACTIVE ART
Students interact with the reactants and products of photosynthesis.

TUTOR TUBE
Short, online tutorials help students identify the reactants and products of photosynthesis.

ART IN MOTION
This short animation shows how the light-dependent reactions of photosynthesis proceed.

ART REVIEW
Students drag and drop figure labels to explore the light-independent reactions.

DATA ANALYSIS
Students gather and analyze data about photosynthesis in marine algae.
LESSON 8.1

Getting Started

Objectives
8.1.1 Describe the role of ATP in cellular activities.
8.1.2 Explain where plants get the energy they need to produce food.

Student Resources
Study Workbooks A and B, 8.1 Worksheets
Spanish Study Workbook, 8.1 Worksheets

ACTIVATE PRIOR KNOWLEDGE
Show students a living plant, and ask what they think would happen if the plant were watered but kept away from light for several weeks. (The plant would probably turn yellow and not grow much.) Then, ask how plants use light to survive and grow. (They use the energy from sunlight to carry out photosynthesis.) Tell students that in this chapter they will learn how plant cells capture and use the energy in sunlight.

UNIFYING CONCEPTS AND PROCESSES
I, V

CONTENT
C.1.b, C.4.b, C.5.a, C.5.b, C.5.c, C.5.d

THINK ABOUT IT
Homeostasis is hard work. Just to stay alive, organisms and the cells within them have to grow and develop, move materials around, build new molecules, and respond to environmental changes. Plenty of energy is needed to accomplish all this work. What powers so much activity, and where does that power come from?

Chemical Energy and ATP

Why is ATP useful to cells?

Energy is the ability to do work. Nearly every activity in modern society depends upon energy. When a car runs out of fuel—more precisely, out of the chemical energy in gasoline—it comes to a sputtering halt. Without electrical energy, lights, appliances, and computers stop working. Living things depend on energy, too. Sometimes the need for energy is easy to see. It takes plenty of energy to play soccer or other sports. However, there are times when that need is less obvious. Even when you are sleeping, your cells are quietly busy using energy to build new molecules, contract muscles, and carry out active transport. Simply put, without the ability to obtain and use energy, life would cease to exist.

Energy comes in many forms, including light, heat, and electricity. Energy can be stored in chemical compounds, too. For example, when you light a candle, the wax melts, soaks into the wick, and is burned. As the candle burns, chemical bonds between carbon and hydrogen atoms in the wax are broken. New bonds then form between these atoms and oxygen, producing CO2 and H2O (carbon dioxide and water). These new bonds are at a lower energy state than the original chemical bonds in the wax. The energy lost is released as heat and light in the glow of the candle’s flame.

Living things use chemical fuels as well. One of the most important compounds that cells use to store and release energy is adenosine triphosphate (ATP), abbreviated ATP. As shown in Figure 8–1, ATP consists of adenine, a 5-carbon sugar called ribose, and three phosphate groups. As you’ll see, those phosphate groups are the key to ATP’s ability to store and release energy.

FIGURE 8–1 ATP is the basic energy source used by all types of cells.
Storing Energy  Adenosine diphosphate (ADP) is a compound that looks almost like ATP, except that it has two phosphate groups instead of three. This difference is the key to the way in which living things store energy. When a cell has energy available, it can store small amounts of it by adding phosphate groups to ADP molecules, producing ATP. As seen in Figure 8–2, ADP is like a rechargeable battery that powers the machinery of the cell.

Releasing Energy  Cells can release the energy stored in ATP by the controlled breaking of the chemical bonds between the second and third phosphate groups. Because a cell can add or subtract these phosphate groups, it has an efficient way of storing and releasing energy as needed. ATP can easily release and store energy by breaking and re-forming the bonds between its phosphate groups. This characteristic of ATP makes it exceptionally useful as a basic energy source for all cells.

Using Biochemical Energy  One way cells use the energy provided by ATP is to carry out active transport. Many cell membranes contain sodium-potassium pumps, membrane proteins that pump sodium ions (Na⁺) out of the cell and potassium ions (K⁺) into it. ATP provides the energy that keeps this pump working, maintaining a carefully regulated balance of ions on both sides of the cell membrane. In addition, ATP powers movement, providing the energy for motor proteins that contract muscle and power the wavelike movement of cilia and flagella.

Energy from ATP powers other important events in the cell, including the synthesis of proteins and responses to chemical signals at the cell surface. The energy from ATP can even be used to produce light. In fact, the blink of a firefly on a summer night comes from an enzyme that is powered by ATP!

ATP is such a useful source of energy that you might think cells would be packed with ATP to get them through the day—but this is not the case. In fact, most cells have only a small amount of ATP—enough to last for a few seconds of activity. Why? Even though ATP is a great molecule for transferring energy, it is not a good one for storing large amounts of energy over the long term. A single molecule of the sugar glucose, for example, stores more than 90 times the energy required to add a phosphate group to ADP to produce ATP. Therefore, it is more efficient for cells to keep only a small supply of ATP on hand. Instead, cells can regenerate ATP from ADP as needed by using the energy in foods like glucose. As you will see, that’s exactly what they do.

In Your Notebook  With respect to energy, how are ATP and glucose similar? How are they different?

Biology In-Depth

PHOTOAUTOTROPHS AND CHEMOAUTOTROPHS

In this chapter, students are introduced to autotrophs. In Chapter 20, they will learn about a major distinction among autotrophs. The autotrophs discussed here are called photoautotrophs, or organisms that use light energy to produce food. Autotrophs also include chemoautotrophs, which are organisms that use energy directly from chemical compounds to produce carbon molecules. For example, prokaryotes that live deep in the ocean near hydrothermal vents are chemoautotrophs. They derive energy from chemical compounds in the waters emerging from vents.

Teach

Use Visuals

Use Figure 8–1 to discuss where chemical energy is stored in a chemical compound and how ATP can easily store and release energy.

Ask Where is energy stored in the molecule of ATP? (In the chemical bonds that hold the parts of the molecule together, represented in the figure by thin black lines.)

Ask How would you change the figure to show a molecule of ADP? (Take away the third phosphate group and the bond that holds it to the molecule.)

DIFFERENTIATED INSTRUCTION

Advanced Students  Ask students to search the Internet for amazing facts about ATP. For example, have them find out how often an ATP molecule gains and loses a phosphate group, how much ATP is consumed during vigorous exercise, or how much ATP is generated in the body per second—any facts they can find that they think are amazing. Ask them to report the facts to the class.

Students can further explore the analogy in Figure 8–2 by watching Visual Analogy: ATP as a Charged Battery.

Answers

FIGURE 8–2  The beam produced by the ATP-“powered” flashlight is much brighter than the beam produced by the ADP-“powered” flashlight because ATP contains more stored energy than ADP.

IN YOUR NOTEBOOK  Similar: both store energy in their chemical bonds; Different: a single molecule of glucose stores 90 times more energy than a molecule of ATP, but ATP is much more useful for transferring energy than is glucose.

Photosynthesis  227
**Heterotrophs and Autotrophs**

*What happens during the process of photosynthesis?*

Cells are not “born” with a supply of ATP—they must somehow produce it. So, where do living things get the energy they use to produce ATP? The simple answer is that it comes from the chemical compounds that we call food. Organisms that obtain food by consuming other living things are known as heterotrophs. Some heterotrophs get their food by eating plants such as grasses. Other heterotrophs, such as the cheetah in Figure 8–3, obtain food from plants indirectly by feeding on plant-eating animals. Still other heterotrophs—mushrooms, for example—obtain food by absorbing nutrients from decomposing organisms in the environment.

Originally, however, the energy in nearly all food molecules comes from the sun. Plants, algae, and some bacteria are able to use light energy from the sun to produce food. Organisms that make their own food are called autotrophs. Ultimately, nearly all life on Earth, including ourselves, depends on the ability of autotrophs to capture the energy of sunlight and store it in the molecules that make up food. The process by which autotrophs use the energy of sunlight to produce high-energy carbohydrates—sugars and starches—that can be used as food is known as photosynthesis. Photosynthesis comes from the Greek words photo, meaning “light,” and synthesis, meaning “putting together.” Therefore, photosynthesis means “using light to put something together.”

In the process of photosynthesis, plants convert the energy of sunlight into chemical energy stored in the bonds of carbohydrates. In the rest of this chapter, you will learn how this process works.

**Assess and Remediate**

**Evaluate Understanding**

Call on students at random to explain the difference between autotrophs and heterotrophs. Then, have them complete the 8.1 Assessment.

**Remediation Suggestion**

For Struggling Students:

- If your students have trouble with Question 2c, suggest they read the definition of decomposer in the Glossary.

**Assessment Answers**

1a. ATP is an abbreviation for the compound adenosine triphosphate. Cells use ATP to store and release energy.

1b. ATP can easily release and store energy by breaking and re-forming the bonds between its phosphate groups.

1c. ADP and ATP are like batteries because they store energy in the chemical bonds they contain. ADP has only two phosphate groups (and fewer bonds), so it’s like a partially charged battery. ATP has three phosphate groups, so it is like a fully charged battery and has more bonds available for energy storage.

2a. the sun

2b. Heterotrophs obtain energy by feeding on other living things. Autotrophs, by contrast, make their own food.

2c. Decomposers consume the remains of living things for energy and cannot make their own food.

3. Sample answer: Photosynthesis provides the base for the one-way flow of energy through the biosphere. Plants convert energy from the sun into sugars, which provide fuel for themselves and for other organisms. Photosynthesis also cycles carbon and oxygen nutrients through the biosphere.
Understanding Photosynthesis  Many scientists have contributed to understanding how plants carry out photosynthesis. Early research focused on the overall process. Later, researchers investigated the detailed chemical pathways.

**1650**  **1700**  **1750**  **1800**  **1850**  **1900**  **1950**  **2000**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1643</td>
<td>After analyzing his measurements of a willow tree’s water intake and mass increase, Jan van Helmont concludes that trees gain most of their mass from water.</td>
</tr>
<tr>
<td>1771</td>
<td>Joseph Priestley experiments with a bell jar, a candle, and a plant and concludes that the plant releases oxygen.</td>
</tr>
<tr>
<td>1779</td>
<td>Jan Ingenhousz finds that aquatic plants produce oxygen bubbles in the light but not in the dark. He concludes that plants need sunlight to produce oxygen.</td>
</tr>
<tr>
<td>1845</td>
<td>Julius Robert Mayer proposes that plants convert light energy into chemical energy.</td>
</tr>
<tr>
<td>1948</td>
<td>Melvin Calvin traces the chemical path that carbon follows to form glucose. These reactions are also known as the Calvin cycle.</td>
</tr>
<tr>
<td>1992</td>
<td>Rudolph Marcus wins the Nobel Prize in chemistry for describing the process by which electrons are transferred from one molecule to another in the electron transport chain.</td>
</tr>
<tr>
<td>2004</td>
<td>So Iwata and Jim Barber identify the precise mechanism by which water molecules are split in the process of photosynthesis. Their research may one day be applied to artificial photosynthesis technologies in order to produce a cheap supply of hydrogen gas that can be used as fuel.</td>
</tr>
</tbody>
</table>

Use the Internet or library resources to research the experiments conducted by one of these scientists. Then, write a summary describing how the scientist contributed to the modern understanding of photosynthesis. Make sure students cite their sources of information, either by including the publication information for a book or the address of a reliable Web site.

**Writing** Summaries will vary. Students’ summaries should provide basic information about how one of the scientists included on the time line contributed to the understanding of photosynthesis. Make sure students cite their sources of information, either by including the publication information for a book or the address of a reliable Web site.

**Answers**

**Writing** Summaries will vary. Students’ summaries should provide basic information about how one of the scientists included on the time line contributed to the understanding of photosynthesis. Make sure students cite their sources of information, either by including the publication information for a book or the address of a reliable Web site.

**How Science Works**

**Priestley’s Experiment “Purifies” Air**

Joseph Priestley (1733–1804), a British Unitarian minister, never formally studied science. His interest in science was encouraged when he met Benjamin Franklin in London in the 1760s. For one of his many experiments, Priestley used an apparatus that consisted of enclosed containers of air, sealed at the bottom by a trough of mercury. He discovered that a burning candle in one of the closed containers caused the air to become “impure,” eventually putting out the flame. He also found that a mouse placed inside the container of “impure” air died. He expected the same to happen to a sprig of spearmint. Much to his surprise, instead of dying, the plant flourished. Furthermore, he discovered that the plant “purified” the air, since after leaving the plant in the space for several weeks, a candle would burn or a mouse could live in the same enclosed space.
LESSON 8.2 • Lesson Overview  • Lesson Notes  • Data Analysis

0224_mlbio10_Ch08.indd   70224_mlbio10_Ch08.indd   7 6/29/09   5:27:25 PM

LESSON 8.2

A.1.b, A.2.a

INQUIRY

B.6, C.1.b, C.1.e, C.5.a, C.5.b

CONTENT

II, III

UNIFYING CONCEPTS AND PROCESSES

Student Resources

Study Workbooks A and B, 8.2 Worksheets
Spanish Study Workbook, 8.2 Worksheets

Taking Notes

Outline  Make an outline using the green and blue headings in this lesson. Fill in details as you read to help you organize the information.


Build Background

As students observe, pass light through a prism. They should observe that the light separates into the colors of the rainbow. Explain that white light is made up of different colors of light, each with a different wavelength, and the separation occurs because each different wavelength of light refracts, or bends, a different amount. Then, have students look at the graph in Figure 8–4. Point out that the graph shows photosynthetic pigments absorb some colors well but do not absorb other colors well.

THINK ABOUT IT  How would you design a system to capture the energy of sunlight and convert it into a useful form? First, you’d have to collect that energy. Maybe you’d spread out lots of flat panels to catch the light. You might then coat the panels with light-absorbing compounds, but what then? Could you take the energy, trapped ever so briefly in these chemical compounds, and get it into a stable, useful, chemical form? Solving such problems may well be the key to making solar power a practical energy alternative. But plants have already solved all these issues on their own terms—and maybe we can learn a trick or two from them.

Chlorophyll and Chloroplasts

What role do pigments play in the process of photosynthesis? Our lives, and the lives of nearly every living thing on the surface of Earth, are made possible by the sun and the process of photosynthesis. In order for photosynthesis to occur, light energy from the sun must somehow be captured.

Light  Energy from the sun travels to Earth in the form of light. Sunlight, which our eyes perceive as “white” light, is actually a mixture of different wavelengths. Many of these wavelengths are visible to our eyes and make up what is known as the visible spectrum. Our eyes see the different wavelengths of the visible spectrum as different colors: shades of red, orange, yellow, green, blue, indigo, and violet.

Pigments  Plants gather the sun’s energy with light-absorbing molecules called pigments. Photosynthetic organisms capture energy from sunlight with pigments. The plants’ principal pigment is chlorophyll (kla’far uh fil’). The two types of chlorophyll found in plants, chlorophyll a and chlorophyll b, absorb light very well in the blue-violet and red regions of the visible spectrum. However, chlorophyll does not absorb light well in the green region of the spectrum, as shown in Figure 8–4.

Photosynthesis: An Overview

Key Questions

What role do pigments play in the process of photosynthesis?
What are electron carrier molecules?
What are the reactants and products of photosynthesis?

Vocabulary

pigment • chlorophyll • thylakoid • stroma • NADP+ • light-dependent reactions • light-independent reactions

FIGURE 8–4  Light Absorption

Light Absorption by Photosynthetic Pigments

Estimated Absorption (%)

Chlorophyll a  Chlorophyll b  Carotenoids

Wavelength (nm)

400 450 500 550 600 650 700 750

Y  B  G  Y  O  R

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

II, III

CONTENT

B.6, C.1.b, C.1.e, C.5.a, C.5.b

INQUIRY

A.1.b, A.2.a

Teach for Understanding

ENDURING UNDERSTANDING  A cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive.

GUIDING QUESTION  What cellular structures and molecules are involved in photosynthesis?

EVIDENCE OF UNDERSTANDING  After students have finished the lesson, this assessment should show their understanding of the structures and processes involved in photosynthesis. Have students work in small groups. Have each group member choose one or more of the following elements of photosynthesis: sunlight, chlorophyll molecule, chloroplast, high-energy electrons, light-dependent reactions, light-independent reactions. Have group members imagine they are their chosen elements and offer a first-person explanation of how they are involved in the process of photosynthesis.

Taking Notes

Make an outline using the green and blue headings in this lesson. Fill in details as you read to help you organize the information.

Figure 8–4. Light Absorption by Photosynthetic Pigments

Estimated Absorption (%)

Chlorophyll a  Chlorophyll b  Carotenoids

Wavelength (nm)

400 450 500 550 600 650 700 750

Y  B  G  Y  O  R

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Leaves reflect green light, which is why plants look green. Plants also contain red and orange pigments such as carotene that absorb light in other regions of the spectrum. Most of the time, the intense green color of chlorophyll overwhelms the accessory pigments, so we don’t notice them. As temperatures drop late in the year, however, chlorophyll molecules break down first, leaving the reds and oranges of the accessory pigments for all to see. The beautiful colors of fall in some parts of the country are the result of this process.

**Chloroplasts** Recall from Chapter 7 that in plants and other photosynthetic eukaryotes, photosynthesis takes place inside organelles called chloroplasts. Chloroplasts contain an abundance of saclike photosynthetic membranes called **thylakoids** (rruh luh koydz). Thylakoids are interconnected and arranged in stacks known as grana (singular: granum). Pigments such as chlorophyll are located in the thylakoid membranes. The fluid portion of the chloroplast, outside of the thylakoids, is known as the **stroma**. The structure of a typical chloroplast is shown in Figure 8–5.

**Energy Collection** What’s so special about chlorophyll that makes it important for photosynthesis? Because light is a form of energy, any compound that absorbs light absorbs energy. Chlorophyll absorbs visible light especially well. In addition, when chlorophyll absorbs light, a large fraction of that light energy is transferred directly to electrons in the chlorophyll molecule itself. By raising the energy levels of these electrons, light energy can produce a steady supply of high-energy electrons, which is what makes photosynthesis work.

**In Your Notebook** In your own words, explain why most plants will not grow well if kept under green light.

**Quick Facts**

**PHOTOSYNTHETIC PIGMENTS** There are three main kinds of photosynthetic pigments in living things.

1. Chlorophylls—green pigments
   - Chlorophyll a is found in all plants, algae, and cyanobacteria.
   - Chlorophyll b is found in all plants and green algae.
   - Chlorophyll c is found in diatoms and brown algae.
   - Chlorophyll d is found in red algae.

2. Carotenoids—red, orange, or yellow pigments
   - Carotene is found in most plants and some algae.
   - Carotene gives carrots their color.
   - Fucoxanthin is found in brown algae and diatoms.

3. Phycobilins—blue or red pigments
   - Phycobilins are found only in red algae and cyanobacteria.
   - Some phycobilins are fluorescent.

**Teach**

**ZOOMING IN**

Have students use Figure 8–5 to discuss the location and structure of the chloroplast. Point out that the figure shows a leaf, a cell within the leaf, and a chloroplast within the cell. Then, make a Two-Column Table on the board. Title the left column **Structure**, and write the names of all the chloroplast structures that are labeled in the figure. Title the right column **Description**. Call on students to provide descriptions or definitions of each structure.

**Study Wkbks A/B**, Appendix S31, Two-Column Table. **Transparencies**, GO16.

**DIFFERENTIATED INSTRUCTION**

**ELL** Struggling Students Provide students with an unlabeled drawing of a chloroplast, similar to the chloroplast in the figure. Then, have students work in pairs to label the structures on their drawing.

**ELL** Focus on ELL: Access Content

**ADVANCED AND ADVANCED HIGH SPEAKERS**

To help students understand the relationship between color and light absorption, assign them a **Problem and Solution** activity. Ask students: What change would you see in a plant whose chlorophyll pigments suddenly stop working? Have them refer to Figure 8–4 and write a three- to four-sentence response. Then, have them present their solutions to the class. Students should infer that the plant’s leaves would change color from green to yellow, orange, or red.

**Study Wkbks A/B**, Appendix S9, Problem and Solution.

**Answers**

**FIGURE 8–5** in stacks known as grana

**IN YOUR NOTEBOOK** Sample answer: Plants need to be able to absorb energy from the sun to photosynthesize and grow. Chlorophyll in plants does not absorb green light well—it reflects it. Because chlorophyll is the principal pigment in plants that captures energy from sunlight, plants under green light will not capture enough energy.
LESSON 8.2

Teach continued

Lead a Discussion

Explain that electron carriers are compounds that can transfer electrons energized by sunlight to a chemical reaction elsewhere in the cell.

Ask In the conversion of NADP⁺ to NADPH, what happens to the energy absorbed by chlorophyll from sunlight? (The conversion of NADP⁺ to NADPH traps the energy of sunlight in chemical form.)

DIFFERENTIATED INSTRUCTION

LPR Less Proficient Readers Make a Flowchart on the board to clarify the role of electron carriers in photosynthesis. Use these steps:

2. Absorption of light produces high-energy electrons.
3. Each electron carrier NADP⁺ picks up 2 high-energy electrons and 1 hydrogen ion.
4. Picking up the electrons and the hydrogen ion changes NADP⁺ into NADPH.
5. NADPH carries the high-energy electrons to chemical reactions elsewhere in the cell.

As you write each step, point out where in the text this step is discussed. Have students copy the flowchart in their notebook.


Ask students what the oven mitt represents. (the electron carrier NADP⁺) Make sure they understand the mitt picks up more than just the “hot potato,” representing 2 high-energy electrons. Ask what else the electron carrier picks up. (a hydrogen ion)

Students can further explore the analogy of oven mitts and electron carriers in Visual Analogy: Carrying Electrons.

Discuss with students why it would have seemed logical to van Helmont to conclude that water provided the extra mass. (He watered the plant regularly.) Then, point to the overall reaction for photosynthesis for the answer to the question. (CO₂) Students can go online to Biology.com to gather their evidence.

High-Energy Electrons

What are electron carrier molecules?

In a chemical sense, the high-energy electrons produced by chlorophyll are highly reactive and require a special “carrier.” Think of a high-energy electron as being similar to a hot potato straight from the oven. If you wanted to move the potato from one place to another, you wouldn’t pick it up in your hands. You would use an oven mitt—a carrier—to transport it, as shown in Figure 8–6. Plant cells treat high-energy electrons in the same way. Instead of an oven mitt, however, they use electron carriers to transport high-energy electrons from chlorophyll to other molecules. An electron carrier is a compound that can accept a pair of high-energy electrons and transfer them, along with most of their energy, to another molecule.

One of these carrier molecules is a compound known as NADP⁺ (nicotinamide adenine dinucleotide phosphate). The name is complicated, but the job that NADP⁺ has is simple. NADP⁺ accepts and holds 2 high-energy electrons, along with a hydrogen ion (H⁺). This converts the NADP⁺ into NADPH. The conversion of NADP⁺ into NADPH is one way in which some of the energy of sunlight can be trapped in chemical form. The NADPH can then carry the high-energy electrons that were produced by light absorption in chlorophyll to chemical reactions elsewhere in the cell. These high-energy electron carriers are used to help build a variety of molecules the cell needs, including carbohydrates like glucose.

An Overview of Photosynthesis

What are the reactants and products of photosynthesis?

Many steps are involved in the process of photosynthesis. However, the overall process of photosynthesis can be summarized in one sentence. Photosynthesis uses the energy of sunlight to convert water and carbon dioxide (reactants) into high-energy sugars and oxygen (products). Plants then use the sugars to produce complex carbohydrates such as starches, and to provide energy for the synthesis of other compounds, including proteins and lipids.

Because photosynthesis usually produces 6-carbon sugars (C₆H₁₂O₆) as the final product, the overall reaction for photosynthesis can be shown as follows:

In Symbols: 6CO₂ + 6H₂O light → C₆H₁₂O₆ + 6O₂

In Words: Carbon dioxide + Water light → Sugars + Oxygen

Biology In-Depth

WHY BOTH ATP AND NADPH?

Students may wonder why cells need two different forms of a chemical intermediate—or “go between.” Both the phosphate-bond compound ATP and the electron carrier NADPH store a significant amount of chemical energy, and so both are capable of providing the energy needed to make energy-requiring reactions possible. Some reactions, however, specifically require the addition of a pair of electrons, and these include the reactions in the pathways of the Calvin cycle that utilize NADPH. In addition—as students will see when they study cellular respiration—most of the energy-yielding reactions of the Krebs cycle directly yield high-energy electrons. Those high-energy electrons must be passed to an electron carrier in order to produce the ATP needed for other energy-requiring reactions.
Light-Dependent Reactions Although the equation for photosynthesis looks simple, there are many steps to get from the reactants to the final products. In fact, photosynthesis actually involves two sets of reactions. The first set of reactions is known as the light-dependent reactions because they require the direct involvement of light and light-absorbing pigments. The light-dependent reactions use energy from sunlight to produce energy-rich compounds such as ATP. These reactions take place within the thylakoids—specifically, in the thylakoid membranes—of the chloroplast. Water is required in these reactions as a source of electrons and hydrogen ions. Oxygen is released as a byproduct.

Light-Independent Reactions Plants absorb carbon dioxide from the atmosphere and complete the process of photosynthesis by producing carbon-containing sugars and other carbohydrates. During the light-independent reactions, ATP and NADPH molecules produced in the light-dependent reactions are used to produce high-energy sugars from carbon dioxide. As the name implies, no light is required to power the light-independent reactions. The light-independent reactions take place outside the thylakoids, in the stroma.

The interdependent relationship between the light-dependent and light-independent reactions is shown in Figure 8–7. As you can see, the two sets of reactions work together to capture the energy of sunlight and transform it into energy-rich compounds such as carbohydrates.

**In Your Notebook** Create a two-column compare/contrast table that shows the similarities and differences between the light-dependent and light-independent reactions of photosynthesis.

**FIGURE 8–7 The Stages of Photosynthesis** There are two stages of photosynthesis: light-dependent reactions and light-independent reactions. Interpret Diagrams What happens to the ATP and NADPH produced in the light-dependent reactions?

![Diagram of photosynthesis](image)

**Build Vocabulary**

**ACADEMIC WORDS** The noun byproduct means “anything produced in the course of making another thing.” Oxygen is considered a byproduct of the light-dependent reactions of photosynthesis because it is produced as a result of extracting electrons from water. Also, unlike ATP and NADPH, oxygen is not used in the second stage of the process, the light-independent reactions.

**DIFFERENTIATED INSTRUCTION**

**L1 Special Needs** To make sure students understand the difference between the two stages of photosynthesis, call on volunteers to classify each of the following situations as either light-dependent or light-independent.

- Sleeping (light-independent)
- Reading a book (light-dependent)
- Watching a race (light-dependent)
- Listening to music (light-independent)

**ELL English Language Learners** Explain that the prefix in- means “not,” and the word dependent means “relying on.” Then, ask what the word independent means. (not relying on)

**Ask** Which stage of photosynthesis relies on light in order to take place? (the light-dependent reactions)

**Biology.com** By accessing the InterActive Art: Photosynthesis activity, students can learn more about the overall photosynthesis reaction. Suggest students watch the Tutor Tube: Sorting Out Light-Independent and Light-Dependent Reactions for extra help distinguishing between the two stages of photosynthesis.

**Answers**

**FIGURE 8–7** Both ATP and NADPH from the light-dependent reactions are used to produce high-energy sugars in the light-independent reactions.

**In Your Notebook** Students’ tables may vary. A typical table will have one column for light-dependent reactions and the other for light-independent reactions. Included in the rows might be information about the location of reactions, whether light is needed, what reactants are needed, and what products are produced.
Quick Lab

**PURPOSE** Students will be able to conclude that oxygen is produced by plants during photosynthesis.

**MATERIALS** large clear plastic cup, sodium bicarbonate solution, *Elodea* plant, large test tube

**SAFETY** Warn students to handle glass carefully. Students should wash their hands after the lab.

**PLANNING** Prepare the sodium bicarbonate solution by mixing 5 g of sodium bicarbonate into each liter of water. Obtain the *Elodea* plants.

**ANALYZE AND CONCLUDE**

1. bubbles of a gas (up to 30 minutes after setup)
2. oxygen; yes, it would be considered a waste product because the plant released it.
3. the chloroplast

Assess and RemEDIATE

**EVALUATE UNDERSTANDING**

Have students describe how plants produce sugars. Then, have them complete the 8.2 Assessment.

**REMEDIATION SUGGESTION**

Struggling Students If students have trouble with Question 1b, have them refer to Figure 8–4.

Students can then check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

**Assessment Answers**

1a. They capture energy from sunlight.
1b. It would not grow well because chlorophyll does not absorb much light in the yellow region of the visible spectrum.
2a. NADPH transfers high-energy electrons between molecules.
2b. Light energy absorbed by pigments produces high-energy electrons that are used to convert NADP⁺ and ADP to the compounds NADPH and ATP, trapping the energy in chemical form.
2c. Because photosynthesis depends on the conversion of NADP⁺ to NADPH to carry electrons to chemical reactions in other parts of the cell, the process could not occur efficiently if there were a shortage of NADP⁺ in the cells of plants.
3a. Photosynthesis uses the energy of sunlight to convert water and carbon dioxide (reactants) into high-energy sugars and oxygen (products).
3b. Light-dependent reactions: sunlight and water enter; oxygen is lost as a byproduct; ATP and NADPH are produced. Light-independent reactions: carbon dioxide enters; glucose is made using the energy provided by ATP and NADPH; ADP and NADP⁺ are cycled back for re-use in the light-dependent reactions.
3c. Infer How would photosynthesis be affected if there were a shortage of NADP⁺ in the cells of plants?

**Visual Thinking**

4. Diagrams should have labels for the thylakoids, grana, and stroma and should indicate that the light-dependent reactions occur in the thylakoids and the light-independent reactions occur in the stroma.
5. Draw two leaves—one green and one orange. Using colored pencils, markers, or pens, show which colors of visible light are absorbed and reflected by each leaf.
The Process of Photosynthesis

THINK ABOUT IT Why membranes? Why do chloroplasts contain so many membranes? Is there something about biological membranes that makes them absolutely essential for the process of photosynthesis? As you’ll see, there is. When most pigments absorb light, they eventually lose most of that energy as heat. In a sense, the “trade secret” of the chloroplast is how it avoids such losses, capturing light energy in the form of high-energy electrons—and membranes are the key. Without them, photosynthesis simply wouldn’t work.

The Light-Dependent Reactions: Generating ATP and NADPH

Recall that the process of photosynthesis involves two primary sets of reactions: the light-dependent and the light-independent reactions. The light-dependent reactions encompass the steps of photosynthesis that directly involve sunlight. These reactions explain why plants need light to grow. The light-dependent reactions use energy from sunlight to produce oxygen and convert ADP and NADP+ into the energy carriers ATP and NADPH.

The light-dependent reactions occur in the thylakoids of chloroplasts. Thylakoids are saclike membranes containing most of the machinery needed to carry out these reactions. Thylakoids contain clusters of chlorophyll and proteins known as photosystems. The photosystems, which are surrounded by accessory pigments, are essential to the light-dependent reactions. Photosystems absorb sunlight and generate high-energy electrons that are then passed to a series of electron carriers embedded in the thylakoid membrane. Light absorption by the photosystems is just the beginning of this important process.

FIGURE 8–8 The Importance of Light
Like most plants, this rice plant needs light to grow.

Apply Concepts Which stage of photosynthesis requires light?

Vocabulary
photosystem • electron transport chain • ATP synthase • Calvin cycle

Taking Notes
Flowchart As you read, create a flowchart that clearly shows the steps involved in the light-dependent reactions.

Key Questions
What happens during the light-dependent reactions?
What happens during the light-independent reactions?
What factors affect photosynthesis?

Answers
FIGURE 8–8 the light-dependent reactions

Teach for Understanding

ENDURING UNDERSTANDING A cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive.

GUIDING QUESTION How do photosynthetic organisms convert the sun’s energy into chemical energy?

EVIDENCE OF UNDERSTANDING After students have finished the lesson, this assessment should show their understanding of the steps that make up the process of photosynthesis. Have students work in small groups, and assign each group one of the steps in the process of photosynthesis. (If there are enough groups, you could assign each group the material in one of the subsections marked by the blue heads.) Ask the students in each group to become experts on that step and make a presentation to the class explaining what happens. Groups should be prepared to take questions from classmates.

GETTING STARTED

Objectives
8.3.1 Describe what happens during the light-dependent reactions.
8.3.2 Describe what happens during the light-independent reactions.
8.3.3 Identify factors that affect the rate at which photosynthesis occurs.

Student Resources
Study Workbooks A and B, 8.3 Worksheets
Spanish Study Workbook, 8.3 Worksheets
Lab Manual B, 8.3 Data Analysis Worksheet

Answers

UNIFYING CONCEPTS AND PROCESSES
III, V

CONTENT
B.3, B.6, C.1.a, C.1.b, C.1.e, C.5.a, C.5.b

INQUIRY
A.1.a, A.1.c, A.2.a

NATIONAL SCIENCE EDUCATION STANDARDS
Focus on ELL: Build Background

BEGINNING SPEAKERS Have students fill in a Cluster Diagram for the topic of photosynthesis. Ask them to think of words that relate to photosynthesis and write them in boxes connected to the circle. Then, lead a discussion on the words students recorded and how the words relate to photosynthesis. Make sure words not associated with photosynthesis are not validated as such.


Answers

IN YOUR NOTEBOOK Sample answer: Water is needed for the electrons and H⁺ ions used in the reactions of photosynthesis. Sunlight is needed to supply the energy that is absorbed by pigments in chloroplasts, which increases the energy of electrons in photosystems.

How Science Works

SAME STAGES, DIFFERENT NAMES

In the early 1900s, British plant physiologist F. F. Blackman concluded that photosynthesis occurs in two stages, a stage that depends on light followed by a stage that can take place in darkness. The terms light reactions and dark reactions have been commonly used for the two stages since that time. Yet, the term dark reactions implies that those reactions can occur only in darkness, which is not the case. It’s just that the dark reactions do not depend on sunlight. To avoid ambiguity, the authors of many modern textbooks have labeled the two stages light-dependent reactions and light-independent reactions. Some authors have gone a step further toward clarity by labeling the light-independent reactions the Calvin cycle, the name of the series of reactions that make up the light-independent reactions in most photosynthetic organisms.
**Quick Facts**

**THE H⁺ ION IN PHOTOSYNTHESIS**

One of the important events in the light-dependent reactions is the removal of electrons and H⁺ ions from water molecules. Both the electrons and the H⁺ ions play important roles in the production of ATP and NADPH. Another way to identify the H⁺ ions would be to simply call them protons. A hydrogen atom consists of 1 proton and 1 electron. An H⁺ ion, then, is a hydrogen atom without its electron—that is, an H⁺ ion is 1 proton. Therefore, the buildup of hydrogen ions in the thylakoid space is, to put it another way, a buildup of protons.

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** Many students may find interpreting Figure 8–10 difficult. Redraw the figure in simplified form on the board, using a line to represent the thylakoid membrane and four circles to represent the two photosystems and a protein in between and to the right. Ask students to tell you where to draw sunlight hitting the photosystems. Show how electrons move down the chain and hydrogen ions build up in the thylakoid space. Draw an ATP synthase molecule on the line, and then have students tell you how to draw the production of ATP as H⁺ ions pass through the ATP synthase.

**Ask** What happens to the ATP molecules produced as H⁺ ions pass through ATP synthase? (They move to the light-independent reactions.)

**Advanced Students** Encourage interested students to work together to use what they’ve learned about the oxygen produced by photosynthesis to make a poster showing the value in conserving the great forests of the world, including the Amazon rain forest. Suggest they use online or library resources to investigate how the oxygen produced by plants benefits the whole biosphere.

To see how ATP is produced through the rotation of ATP synthase, suggest students watch Art in Motion: Light-Dependent Reactions.
LESSON 8.3

Teach continued

Use Figure 8–11 to discuss the main steps of the light-independent reactions. Call on a volunteer to read aloud the annotation, Carbon Dioxide Enters the Cycle. Then call on another student to read the annotation Sugar Production.

Ask Where do the light-independent reactions occur? (in the stroma of the chloroplast)
Ask What products of the light-dependent reactions are used in the light-independent reactions? (the electron carriers ATP and NADPH)
Ask What is the main product of the Calvin cycle? (sugars and other compounds)

DIFFERENTIATED INSTRUCTION

Struggling Students Some students may have a difficult time understanding the light-independent reactions as presented in Figure 8–11. Simplify the information by writing the important concepts on the board:

- The light-independent reactions occur in the stroma of the chloroplast.
- ATP and NADPH molecules produced in the light-dependent reactions enter the stroma.
- Carbon dioxide molecules from the atmosphere combine with other carbon molecules in the stroma to begin the cycle.
- Energy from ATP and NADPH is used to produce high-energy sugars in the Calvin cycle, another name for the light-independent reactions.

English Language Learners Have students look up stable in a dictionary to find a definition that best fits the context in which it is used here: ATP and NADPH are not stable enough to store energy for more than a few minutes. Point out that stable is a good description of the high-energy sugars produced in photosynthesis, but not a good description of the electron carriers ATP and NADPH.

Check for Understanding

DEPTH OF UNDERSTANDING

Ask Why is the conversion of ADP and NADP+ to ATP and NADPH essential for cell function?

Students with a superficial understanding of photosynthesis might simply say these compounds carry energy. Students with a more sophisticated understanding will be able to explain that the formation of these compounds is the result of the conversion of energy from sunlight to chemical energy in the light-dependent reactions, which is then used in the light-independent reactions to produce the high-energy sugars that provide energy for cell processes.

ADJUST INSTRUCTION

Have students create a flowchart to show energy flow in photosynthesis.
Carbon Dioxide Enters the Cycle

Carbon dioxide molecules enter the Calvin cycle from the atmosphere. An enzyme in the stroma of the chloroplast combines these carbon dioxide molecules with 5-carbon compounds that are already present in the organelle, producing 3-carbon compounds that continue into the cycle. For every 6 carbon dioxide molecules that enter the cycle, a total of twelve 3-carbon compounds are produced. Other enzymes in the chloroplast then convert these compounds into higher-energy forms in the rest of the cycle. The energy for these conversions comes from ATP and high-energy electrons from NADPH.

Sugar Production

At midcycle, two of the twelve 3-carbon molecules are removed from the cycle. This is a very special step because these molecules become the building blocks that the plant cell uses to produce sugars, lipids, amino acids, and other compounds. In other words, this step in the Calvin cycle contributes to all of the products needed for plant metabolism and growth.

The remaining ten 3-carbon molecules are converted back into six 5-carbon molecules. These molecules combine with six new carbon dioxide molecules to begin the next cycle.

Summary of the Calvin Cycle

The Calvin cycle uses 6 molecules of carbon dioxide to produce a single 6-carbon sugar molecule. The energy for the reactions that make this possible is supplied by compounds produced in the light-dependent reactions. As photosynthesis proceeds, the Calvin cycle works steadily, removing carbon dioxide from the atmosphere and turning out energy-rich sugars. The plant uses the sugars to meet its energy needs and to build macromolecules needed for growth and development, including lipids, proteins, and complex carbohydrates such as cellulose. When other organisms eat plants, they, too, can use the energy and raw materials stored in these compounds.

The End Results

The two sets of photosynthetic reactions work together—the light-dependent reactions trap the energy of sunlight in chemical form, and the light-independent reactions use that chemical energy to produce stable, high-energy sugars from carbon dioxide and water. And, in the process, animals, including ourselves, get plenty of food and an atmosphere filled with oxygen. Not a bad deal at all!

In Your Notebook

What happens to the NADP+, ADP, and sugars produced by the Calvin cycle?

Biology In-Depth

THAT PESKY CRAB GRASS

C4 plants (discussed on page 241) have modified pathways that allow them to photosynthesize under harsh conditions. If students live in an area where most houses have their own lawns, they may be familiar with the battle many homeowners fight with a plant commonly called crab grass. Crab grass grows along with ordinary grass, and early in the growing season crab grass may not even be noticeable. In late summer, though, when many lawns dry out and become brown, patches of crab grass remain green and outgrow ordinary grass, creating unsightly patches. Why does crab grass do so well when ordinary grass struggles in late summer? Digitaria sanguinalis, as crab grass is properly known, is a C4 plant, whereas most common grasses are C3 plants. The C4 pathway enables crab grass to thrive under conditions where ordinary grasses grow slowly or start to turn brown.

Lead a Discussion

Some students may have difficulty following the events described when carbon dioxide enters the Calvin cycle. Help them understand the number of 3-carbon compounds produced by working through the math on the board.

Ask How many carbon atoms does a molecule of CO₂ contain? (1)
Ask When a carbon dioxide molecule combines with a 5-carbon compound, how many 3-carbon compounds are produced? (two, because 1 + 5 = 6; 6 ÷ 3 = 2)
Ask If for every carbon dioxide molecule that enters the cycle, two 3-carbon compounds are produced, then how many 3-carbon compounds are produced when six carbon dioxide molecules enter the cycle? (twelve, because 2 x 6 = 12)

DIFFERENTIATED INSTRUCTION

Struggling Students

Some students may have a hard time following the steps of the light-independent reactions. To help these students, read aloud a sentence from the text and then call attention to that step as shown in Figure 8–11. Continue this process through the Calvin cycle.

Discuss with students what product of photosynthesis contains carbon atoms. Suggest they look back to the overall equation for photosynthesis. Students can go online at Biology.com to gather their evidence.

Address Misconceptions

Increase of Matter From a Gas Some students may have difficulty understanding that photosynthesis uses a gas—carbon dioxide—to produce solid sugars. Address this concept by showing students an orange. Most students know oranges contain sugars. Address this concept by showing students an orange. Most students know oranges contain sugars. Write the formula for glucose on the board: C₆H₁₂O₆. Explain that an orange contains glucose. Then, ask what molecule enters the Calvin Cycle that contains carbon, symbolized by C. (carbon dioxide) Explain that the carbon in carbon dioxide contributes the carbon atoms in glucose. Therefore, through photosynthesis, a gas is used to make a solid.

Answers

IN YOUR NOTEBOOK ADP and NADP⁺ become available to pick up more high-energy electrons from the light-dependent reactions. High-energy sugars are used to meet energy needs or are converted to other materials used for growth and development.
Build Science Skills

Explain that scientists make predictions about natural occurrences based on evidence, experience, and knowledge. Have students work in small groups to predict how and why the rate of photosynthesis in plants would be affected by each of the following situations.

- An area in the Midwest experienced a drought that lasted for months. Lakes and rivers dropped to levels lower than anyone could remember.
- During August in a New England city, the temperature rose every day to 37–38°C (98.6–104°F).
- A series of huge volcanoes erupted, and the volcanic ash accumulated in Earth’s atmosphere, reducing the intensity of sunlight for many days.

DIFFERENTIATED INSTRUCTION

**LPR Less Proficient Readers** Struggling readers may stumble over the phrase “intensity of light.” Demonstrate varying intensities by shining a light directly onto a plant and then setting the light on a table a distance from the plant. Ask students which time the light shined more intensely on the plant. *(the closer, direct light)* Then, ask students to describe a condition when the intensity of sunlight is at its maximum. *(sunlight on a summer day when the sun is directly above)*

**LS Advanced Students** Have small groups of students do further research on either C4 photosynthesis or Crassulacean Acid Metabolism (CAM). Ask each group to make a poster that includes drawings and labels explaining the process they researched. Have groups present their posters to the class.

In **Data Analysis: Shedding Light on Marine Algae**, students can gather and analyze data derived from the relationship between light frequency and pigments in marine algae.

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**Answers**

**IN YOUR NOTEBOOK** Enzymes are compounds that speed up chemical reactions, including those involved in photosynthesis.

**PUTS**

**PurPOSE** Students will infer the relationship between photosynthesis and light intensity.

**PLANNING** Tell students that understanding the units of measure along the axes are not as important as recognizing that the rate increases in units of 5 along the y-axis and light intensity increases in units of 200 along the x-axis.

**BUILD Vocabulary**

**MULTIPLE MEANINGS** The noun intensity is commonly used to refer to something or someone who is very emotional, focused, or active. In science, however, intensity refers to energy. Thus, light intensity is a measure of the amount of energy available in light. More intense light has more energy.

**LPR Less Proficient Readers**

- Sun plants may stumble over the phrase “intensity of light.”
- Demonstrate varying intensities by shining a light directly onto a plant and then setting the light on a table a distance from the plant. Ask students which time the light shined more intensely on the plant. *(the closer, direct light)* Then, ask students to describe a condition when the intensity of sunlight is at its maximum. *(sunlight on a summer day when the sun is directly above)*

**LS Advanced Students**

- Have small groups of students do further research on either C4 photosynthesis or Crassulacean Acid Metabolism (CAM). Ask each group to make a poster that includes drawings and labels explaining the process they researched. Have groups present their posters to the class.

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**Factors Affecting Photosynthesis**

**What factors affect photosynthesis?**

**Temperature, Light, and Water**

Many factors influence the rate of photosynthesis. Among the most important factors that affect photosynthesis are temperature, light intensity, and the availability of water. The reactions of photosynthesis are made possible by enzymes that function best between 0°C and 35°C. Temperatures above or below this range may affect those enzymes, slowing down the rate of photosynthesis. At very low temperatures, photosynthesis may stop entirely.

The intensity of light also affects the rate at which photosynthesis occurs. As you might expect, high light intensity increases the rate of photosynthesis. After the light intensity reaches a certain level, however, the plant reaches its maximum rate of photosynthesis.

Because water is one of the raw materials of photosynthesis, a shortage of water can slow or even stop photosynthesis. Water loss can also damage plant tissues. To deal with these dangers, plants (such as desert plants and conifers) that live in dry conditions often have waxy coatings on their leaves that reduce water loss. They may also have biochemical adaptations that make photosynthesis more efficient under dry conditions.

**In Your Notebook**

Explain in your own words what role enzymes play in chemical reactions such as photosynthesis.

**Answers**

1. shade plants
2. about 13–14 μmol CO₂ consumed/m²/s
3. The sun plant will grow less well on the shady forest floor because its rate of photosynthesis will greatly decrease. The graph shows the rate will decrease from about 13 μmol CO₂ consumed/m²/s at 400 μmol photons/m²/s to only about 4 μmol CO₂ consumed/m²/s at 100 μmol photons/m²/s in a shaded forest.

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**Analyzing Data**

**Rates of Photosynthesis**

The rate at which a plant carries out photosynthesis depends in part on environmental factors such as temperature, amount of water available, and light intensity. The graph shows how the average rates of photosynthesis between sun plants and shade plants changes with light intensity.

1. **Use Tables and Graphs** When light intensity is below 200 μmol photons/m²/s, do sun plants or shade plants have a higher rate of photosynthesis?

2. **Infer** Light intensity in the Sonoran Desert averages about 400 μmol photons/m²/s. According to the graph, what would be the approximate rate of photosynthesis for sun plants that grow in this environment?

3. **Form a Hypothesis** Suppose you transplant a sun plant to a shaded forest floor that receives about 100 μmol photons/m²/s. Do you think this plant will grow and thrive? Why or why not? How does the graph help you answer this question?
Photosynthesis Under Extreme Conditions  In order to conserve water, most plants under bright, hot conditions (of the sorts often found in the tropics) close the small openings in their leaves that normally admit carbon dioxide. While this keeps the plants from drying out, it causes carbon dioxide within the leaves to fall to very low levels. When this happens to most plants, photosynthesis slows down or even stops. However, some plants have adapted to extremely bright, hot conditions. There are two major groups of these specialized plants: C4 plants and CAM plants. C4 and CAM plants have biochemical adaptations that minimize water loss while still allowing photosynthesis to take place in intense sunlight.

► C4 Photosynthesis  C4 plants have a specialized chemical pathway that allows them to capture even very low levels of carbon dioxide and pass it to the Calvin cycle. The name “C4 plant” comes from the fact that the first compound formed in this pathway contains 4 carbon atoms. The C4 pathway enables photosynthesis to keep working under intense light and high temperatures, but it requires extra energy in the form of ATP to function. C4 organisms include important crop plants like corn, sugar cane, and sorghum.

► CAM Plants  Other plants adapted to dry climates use a different strategy to obtain carbon dioxide while minimizing water loss. These include members of the family Crassulaceae. Because carbon dioxide becomes incorporated into organic acids during photosynthesis, the process is called Crassulacean Acid Metabolism (CAM). CAM plants admit air into their leaves only at night. In the cool darkness, carbon dioxide is combined with existing molecules to produce organic acids, “trapping” the carbon within the leaves. During the daytime, when leaves are tightly sealed to prevent the loss of water, these compounds release carbon dioxide, enabling carbohydrate production. CAM plants include pineapple trees, many desert cacti, and also the fleshy “ice plants” shown in Figure 8–12, which are frequently planted near freeways along the west coast to retard brush fires and prevent erosion.

**Figure 8–12 CAM Plants** Plants like this ice plant can survive in dry conditions due to their modified light-independent reactions. Air is allowed into the leaves only at night, minimizing water loss.

**Assessment Answers**

1a. The light-dependent reactions use energy from sunlight to produce oxygen and convert ADP and NADP+ into the energy carriers ATP and NADPH.

1b. Sample answer: (1) Light energy is absorbed by electrons in the pigments and water molecules are split into H+ ions, oxygen, and electrons. (2) High-energy electrons (from the splitting of water) move down the electron transport chain, where energy from the electrons is used to pump H+ ions into the thylakoid space. (3) At the end of the chain, NADP+ molecules pick up the high-energy electrons along with H+ ions to become NADPH. (4) H+ ions in the thylakoid space (pumped across in step 2) pass through ATP synthase in the thylakoid membrane, causing the ATP synthase base to rotate and produce ATP.

2a. The Calvin cycle is another name for the light-independent reactions in which ATP and NADPH from the light-dependent reactions are used to produce high-energy sugars. It is named for Melvin Calvin, who worked on its details.

2b. Sample answer: The light-dependent reactions require light and water, occur in the thylakoids, and produce ATP and NADPH. The light-independent reactions require carbon dioxide, occur in the stroma, and produce high-energy sugars.

3a. temperature, light intensity, availability of water

3b. independent variable: light intensity; dependent variable: rate of photosynthesis

4. (to combine with) water

**Expand Vocabulary**

*Minimum* and *maximum* are concepts commonly used in a scientific context. Have students look up *minimize* in a dictionary and then write a sentence explaining what it means to “minimize water loss.”

**DIFFERENTIATED INSTRUCTION**

**ELD English Language Learners** Explain that *minimize* is the verb form of the word *minimum*, which means “the least quantity possible.” Then, explain that the opposite of *minimum* is *maximum*, or “the greatest quantity possible.” The verb form of *maximum* is *maximize.*

**Assess and Remediate**

**EVALUATE UNDERSTANDING**

Ask students to write two short summary paragraphs, one on the light-dependent reactions and another on the light-independent reactions. Then, have them complete the 8.3 Assessment.

**REMEDIATION SUGGESTION**

**Struggling Students** If students have trouble with Question 2b, suggest they look at what is needed to begin each set of reactions and what the products of each set are. Review the difference between the independent variable and the dependent variable in a controlled experiment if students get stuck on Question 3b.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Plant Pigments and Photosynthesis described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Make sure students work in a well-ventilated area. Caution them to avoid breathing the fumes and to use care when handling glassware. Students should wash their hands thoroughly after the lab.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 204.

NATIONAL SCIENCE EDUCATION STANDARDS

CONTENT C.1.e, C.5.b
INQUIRY A.2.b, A.2.c

Pre-Lab: Plant Pigments and Photosynthesis

Problem Do red leaves have the same pigments as green leaves?
Materials paper clips, one-hole rubber stoppers, chromatography paper strips, metric ruler, green and red leaves, coin, sheet of paper, large test tubes, test tube rack, glass-marking pencil, 10-mL graduated cylinder, isopropyl alcohol, colored pencils

Lab Manual Chapter 8 Lab
Skills Focus Predict, Analyze Data, Draw Conclusions

Connect to the Big Idea Almost all life on Earth depends, directly or indirectly, on energy from sunlight. Photosynthesis is the process in which light energy is captured and converted to chemical energy. Many reactions are required for this conversion, which takes place in the chloroplasts of plant cells. Some of the reactions depend on light and some do not. Plant pigments play a major role in the light-dependent reactions. In this lab, you will use chromatography to compare the pigments in red leaves with those in green leaves.

Background Questions
a. Compare and Contrast What do all plant pigments have in common? How are they different?
b. Review Why do most leaves appear green?
c. Review What property makes chlorophyll so important for photosynthesis?

Pre-Lab Questions
Preview the procedure in the lab manual.
1. Design an Experiment What is the purpose of this lab?
2. Control Variables What is the control in this lab?
3. Design an Experiment Why must you place a leaf about 2 cm from the bottom of the paper before rubbing the leaf with the coin?
4. Predict Will red leaves contain the same amount of chlorophyll as green leaves? Why or why not?

Visit Chapter 8 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Journey to Panama with the Untamed Science crew to discover how CO₂ affects plant growth.

Data Analysis Look at pigment color data in the ocean to find out how marine algae photosynthesize in the blue light available underwater.

Tutor Tube Learn how to sort out the products and reactants in both the light-dependent and light-independent reactions.

Art Review Focus on the thylakoid membrane to review your knowledge of the light-dependent reactions.

InterActive Art Bring the components of photosynthesis together to run an animation.

Art in Motion Watch the steps of the light-dependent reactions in motion at the molecular level.

Visual Analogies Compare ATP production to a charged battery. See how the electron transport chain is like passing a hot potato.

Pre-Lab Answers

BACKGROUND QUESTIONS
a. Sample answer: All the pigments are light-absorbing molecules. They differ in how well they absorb different wavelengths of light.
b. Leaves reflect green light because chlorophyll does not absorb light well in the green region of the spectrum.
c. Sample answer: Much of the energy absorbed by chlorophyll molecules is transferred directly to electrons in the chlorophyll molecule.

PRE-LAB QUESTIONS
1. The purpose is to find out whether red leaves have the same pigments as green leaves.
2. Students may say that the green leaf or the chromatogram made from the green leaf is the control.
3. Sample answer: When the strips are placed in the test tube, the pigment line must be above the surface of the alcohol.
4. Sample answer: Red leaves will have less chlorophyll than green leaves because they are not green.
Photosynthesis is the process by which organisms convert light energy into chemical energy that all organisms can use directly, or indirectly, to carry out life functions.

8.1 Energy and Life

ATP can easily release and store energy by breaking and re-forming the bonds between its phosphate groups. This characteristic of ATP makes it exceptionally useful as a basic energy source for all cells.

In the process of photosynthesis, plants convert the energy of sunlight into chemical energy stored in the bonds of carbohydrates.

8.2 Photosynthesis: An Overview

Photosynthetic organisms capture energy from sunlight with pigments.

An electron carrier is a compound that can accept a pair of high-energy electrons and transfer them, along with most of their energy, to another molecule.

Photosynthesis uses the energy of sunlight to convert water and carbon dioxide (reactants) into high-energy sugars and oxygen (products).

8.3 The Process of Photosynthesis

The light-dependent reactions use energy from sunlight to produce oxygen and convert ADP and NADP$^+$ into the energy carriers ATP and NADPH.

During the light-dependent reactions, ATP and NADPH from the light-dependent reactions are used to produce high-energy sugars.

Among the most important factors that affect photosynthesis are temperature, light intensity, and the availability of water.

**Think Visually**
Using the information in this chapter, complete the following flowchart about photosynthesis.

1. **Water**
2. **Oxygen**
3. **ATP**
4. **Calvin cycle**
5. **Sugars**

**Transfer Task**
In a class discussion, have students review the difference between heterotrophs and autotrophs. Point out that now that they have learned about photosynthesis, they should have a much deeper understanding of how autotrophs make their own food, as well as how autotrophs provide heterotrophs with the food they need to produce the ATP used by their cells for energy. Then, ask each student to create a series of scenes that “runs the movie backward”—beginning with a human activity and ending with sunlight being absorbed by chlorophyll. Give students a choice of how they create their scenes. For example, they could draw a series of cartoons, make a flowchart, or write an essay. Explain that they will learn the details in the next chapter of how cells use food to make ATP, but for this task all they need to include on that subject is that a heterotroph’s cells can use food to make ATP.
Lesson 8.1

**UNDERSTAND KEY CONCEPTS**

1. b  
2.  
3.  
4. c  
5. Heterotrophs obtain energy by consuming other organisms; autotrophs obtain energy by consuming the food they make.  
6. An ATP molecule consists of a nitrogen-containing compound called adenine, a 5-carbon sugar called ribose, and three phosphate groups.  
7. A single molecule of glucose stores more than 90 times the energy stored by ATP. ATP, though, transfers energy quickly and is used by the cell as an immediate source of energy.

**THINK CRITICALLY**

8. Answers should include an understanding that ATP stores only a small amount of energy and, thus, is efficient for only short-term storage. Answers should also acknowledge that energy in ATP is stored as chemical bonds, and energy is released when bonds are broken to form ADP and stored when bonds are added to re-form ATP (energy transfer).

9. The Indian pipe plant appears to have no chlorophyll or any other pigment. Without a pigment, this organism cannot carry out photosynthesis to make its own food. Therefore, it must be a heterotroph, which obtains food by consuming other living things.

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Lesson 8.2

**UNDERSTAND KEY CONCEPTS**

10. d  
11.  
12. carbon dioxide + water $\xrightarrow{\text{light}}$ sugars + oxygen  
13. Plant pigments absorb sunlight—the energy source for photosynthesis.  
14. A=stroma; B=granum; C=thylakoid; the light-dependent reactions take place within the thylakoids that make up grana (C and/or B); the light-independent reactions take place in the stroma (A).

**THINK CRITICALLY**

15. The chlorophyll molecules break down first as temperatures drop in the fall, leaving the yellow and red light reflected by the accessory pigments for all to see.

---

**Assessment**

### 8.1 Energy and Life

**Understand Key Concepts**

1. Which of the following are autotrophs?  
   a. deer  
   b. plants  
   c. leopards  
   d. mushrooms

2. The principal chemical compound that living things use to store energy is  
   a. DNA.  
   b. ATP.  
   c. H$_2$O.  
   d. CO$_2$.

3. The amount of energy stored in a molecule of ATP compared to the amount stored in a molecule of glucose is  
   a. greater.  
   b. less.  
   c. the same.  
   d. variable, depending on conditions.

4. When a candle burns, energy is released in the form of  
   a. carbon dioxide and water.  
   b. the chemical substance ATP.  
   c. light and heat.  
   d. electricity and motion.

5. How do heterotrophs and autotrophs differ in the way they obtain energy?  
6. Describe the three parts of an ATP molecule.  
7. Compare the amounts of energy stored by ATP and glucose. Which compound is used by the cell as an immediate source of energy?

**Think Critically**

8. Use Analogies Develop an analogy to explain ATP and energy transfer to a classmate who does not understand the concept.

9. Infer Examine the photograph of the Indian pipe plant shown here. What can you conclude about the ability of the Indian pipe plant to make its own food? Explain your answer.

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**8.2 Photosynthesis: An Overview**

**Understand Key Concepts**

10. In addition to light and chlorophyll, photosynthesis requires  
   a. water and oxygen.  
   b. water and sugars.  
   c. oxygen and carbon dioxide.  
   d. water and carbon dioxide.

11. The leaves of a plant appear green because chlorophyll  
   a. reflects blue light.  
   b. absorbs blue light.  
   c. reflects green light.  
   d. absorbs green light.

12. Write the basic equation for photosynthesis using the names of the starting and final substances of the process.

13. What role do plant pigments play in the process of photosynthesis?

14. Identify the chloroplast structures labeled A, B, and C. In which structure(s) do the light-dependent reactions occur? In which structure(s) do the light-independent reactions take place?

**Think Critically**

15. Form a Hypothesis Although they appear green, some plant leaves contain yellow and red pigments as well as chlorophyll. In the fall, those leaves may become red or yellow. Suggest an explanation for these color changes.

16. Design an Experiment Design an experiment that uses pond water and algae to demonstrate the importance of light energy to pond life. Be sure to identify the variables you will control and the variable you will change.

17. Predict Suppose you water a potted plant and place it by a window in a transparent, airtight jar. Predict how the rate of photosynthesis might be affected over the next few days. What might happen if the plant were left there for several weeks? Explain.

**Sample answer:** Start with two samples of the same type of algae, and place equal amounts of the algae samples in the same amount of pond water. Put one sample in a dark place and the other in a location that receives sunlight daily. Temperatures should be kept the same in both places. After two weeks, compare the two samples to determine the growth and health of the two samples of algae.

**Sample answer:** The plant would grow normally for a short period of time, and then the rate of photosynthesis would drop because of a lack of CO$_2$, which is necessary for carrying out photosynthesis. Eventually, the plant might die, because without the CO$_2$ necessary to carry out photosynthesis, the plant would not have the energy-storing sugars needed to carry out cell activities.
Lesson 8.3

UNDERSTAND KEY CONCEPTS

18. The first process in the light-dependent reactions of photosynthesis is
   a. light absorption.  b. electron transport.  c. oxygen production.  d. ATP formation.
19. Which substance from the light-dependent reactions of photosynthesis is a source of energy for the Calvin cycle?
   a. ADP  b. NADPH  c. H₂O  d. pyruvic acid
20. The light-independent reactions of photosynthesis are also known as the
21. ATP synthase in the chloroplast membrane makes ATP, utilizing the energy of highly concentrated
   a. chlorophyll.  b. electrons.  c. hydrogen ions.  d. NADPH.
22. CAM plants are specialized to survive under what conditions that would harm most other kinds of plants?
   a. low temperatures  b. excess water  c. hot, dry conditions  d. long day lengths
23. Explain the role of NADP⁺ as an energy carrier in photosynthesis.
24. Describe the role of ATP synthase and explain how it works.
25. Summarize the events of the Calvin cycle.
26. Discuss three factors that affect the rate at which photosynthesis occurs.

Think Critically

27. Interpret Graphs Study Figure 8–11 on page 238 and give evidence to support the idea that the Calvin cycle does not depend on light.
28. Apply Concepts How do the events in the Calvin cycle depend on the light-dependent reactions of photosynthesis?
29. Form a Hypothesis Many of the sun’s rays may be blocked by dust or clouds formed by volcanic eruptions or pollution. What are some possible short-term and long-term effects of this on photosynthesis? On other forms of life?

CHAPTER MYSTERY

OUT OF THIN AIR?

Most plants grow out of the soil, of course, and you might hypothesize, as Jan van Helmont did, that soil contributes to plant mass. At the conclusion of his experiment with the willow tree, however, van Helmont discovered that the mass of the soil was essentially unchanged, but that the tree had increased in mass by nearly 75 kilograms. Van Helmont concluded that the mass must have come from water, because water was the only thing he had added throughout the experiment. What he didn’t know, however, was that the increased bulk of the tree was built from carbon, as well as from the oxygen and hydrogen in water. We now know that most of that carbon comes from carbon dioxide in the air. Thus, mass accumulates from two sources: carbon dioxide and water. What form does the added mass take? Think about the origin of the word carbohydrate, from carbo-, meaning “carbon,” and hydrate, meaning “to combine with water,” and you have your answer.

1. Infer Although soil does not significantly contribute to plant mass, how might it help plants grow?
2. Infer If a scientist were able to measure the exact mass of carbon dioxide and water that entered a plant, and the exact mass of the sugars produced, would the masses be identical? Why or why not?
3. Apply Concepts What do plants do with all of the carbohydrates they produce by photosynthesis? (Hint: Plant cells have mitochondria in addition to chloroplasts. What do mitochondria do?)
4. Connect to the Big idea Explain how the experiments carried out by van Helmont and Calvin contributed to our understanding of how nutrients cycle in the biosphere.

Lesson 8.3

H⁺ ions from the thylakoid space pass through the ATP synthase and into the stroma, the ATP synthase molecule rotates and the energy produced is used to convert ADP to ATP.

25. The Calvin cycle uses 6 molecules of carbon dioxide to produce a single 6-carbon sugar molecule. The energy for the reactions that make this possible is supplied by ATP and NADPH, which are produced in the light-dependent reactions. The Calvin cycle works steadily, removing carbon dioxide from the atmosphere and turning out energy-rich sugars.

After students have read through the Chapter Mystery, discuss what van Helmont concluded as well as what he could not know about the process of photosynthesis.

Ask How do you think most people of van Helmont’s time thought trees gained their mass as they grew? (They thought that trees somehow gained their mass by taking in the soil.)

Ask Why couldn’t van Helmont know that trees gained much of their mass through taking in carbon dioxide from the atmosphere? (He didn’t have the modern technology that might have detected how plants use carbon dioxide.)

Ask Van Helmont was right that plants use water to build mass, though he didn’t know how. How do plants use water to increase mass? (Sample answer: Plants use water in the light-dependent reactions of photosynthesis. The water molecules are split, and the electrons and hydrogen ions are picked up by electron carriers and then used in the light-independent reactions to produce high-energy sugars.)

CHAPTER MYSTERY ANSWERS

1. Soil provides a base into which a plant can anchor itself. The soil holds the water that plants take in and use in photosynthesis. The soil provides nutrients the plant needs.
2. The masses would not be identical. The mass of the water and carbon dioxide would be more than the mass of the sugars because the oxygen atoms in water are expelled from the plant cells in the first stage of photosynthesis.
3. Plants use the carbohydrates as a source of energy to carry out cell activities. The mitochondria in plant cells convert the energy in the carbohydrates into compounds that are more convenient for the cells to use.
4. Van Helmont’s work was the beginning of many experiments that led to the understanding that the sources of a plant’s increase in mass are water and carbon dioxide that, through photosynthesis, combine to make sugars. Calvin was able to trace the chemical path carbon follows. Both van Helmont and Calvin contributed to an understanding of photosynthesis, which is involved in the cycling of both oxygen and carbon in the biosphere. Inorganic carbon and hydrogen are combined to form organic sugars. In turn, oxygen is released to the atmosphere.

Students can explore the connection between plant growth, carbon, and photosynthesis deep in the jungles of Panama by watching Soaking Up the CO₂.
26. Sample answer: Because the enzymes that make photosynthesis possible work best between 0°C and 35°C, temperatures above or below this range may slow down the rate of photosynthesis. High light intensity increases the rate of photosynthesis, though after the light intensity reaches a certain level the plant reaches its maximum rate. A shortage of water can slow or even stop photosynthesis.

THINK CRITICALLY
27. No step in the Calvin cycle depends on the presence of light. Instead, the cycle uses energy stored in ATP and NADPH.

28. The energy used in the Calvin cycle comes from ATP and NADPH produced in the light-dependent reactions.

29. Sample answer: If enough of the sun’s rays are blocked, the rate of photosynthesis would slow down. In the short term, plants and other photosynthetic organisms may not grow normally. In the long run, some plants, and organisms that depend on plants, may not survive.

Connecting Concepts

USE SCIENCE GRAPHICS
30. Students’ graphs should show Distance From Light (cm) on the x-axis and Bubbles Produced per Minute on the y-axis. The line should show a curve that descends from left to right.

31. The number of bubbles decreases as the light is placed further away. There would be fewer than 5 bubbles if the light were 50 cm away.

32. The farther the light is from the plant, the fewer the number of bubbles produced. The reason is that a decrease in light intensity results in a decrease in the rate of photosynthesis—and therefore a decrease in oxygen produced.

33. because that is where light intensity is greatest

WRITE ABOUT SCIENCE
34. Stories and illustrations will vary. Students should recognize that both the oxygen atom and the hydrogen atoms enter a chloroplast together as a water molecule, H₂O. The oxygen atom is split from the hydrogen atoms in the light-dependent stage of photosynthesis and leaves the plant as oxygen gas. The hydrogen atoms become involved in the formation of NADPH, the production of ATP, and the production of high-energy sugars in the Calvin cycle.

35. The chloroplasts are specialized to produce sugars such as glucose, but this process cannot occur without an input of energy. The sun’s rays provide that energy, and chlorophyll captures the sun’s rays.

36. Interpret Graphs Bean plants reach their maximum rate of photosynthesis at what concentration of carbon dioxide?
   a. about 50 ppm
   b. about 200 ppm
   c. about 750 ppm
   d. 1600 ppm

37. Draw Conclusions From the data it is possible to conclude that
   a. beans contain more chlorophyll than corn contains.
   b. corn reaches its maximum photosynthetic rate at lower concentrations than beans do.
   c. beans reach their maximum photosynthetic rate at lower concentrations than corn does.
   d. beans use carbon dioxide more efficiently than corn does.

An experiment subject corn plants and bean plants to different concentrations of carbon dioxide and measured the amount of CO₂ taken up by the plants and used in photosynthesis. Data for the two plants are shown in the following graph.

PURPOSE Students will analyze data to understand how varying concentrations of CO₂ affect rates of photosynthesis and that different plants respond to CO₂ concentration in different ways.

PLANNING Review with students factors that affect photosynthesis. Also remind students that a line graph shows how a variable plotted on the vertical axis changes in response to changes in the variable plotted on the horizontal axis. Tell students that understanding the unit of measure for the rate of photosynthesis is not as important as recognizing that the rate increases in units of 20 along the vertical axis. Finally, you may wish to ask students which of the two plants is a C4 plant and how they know. (Corn is C4; it has a higher rate of photosynthesis, even at very low CO₂ concentrations.)

ANSWERS
36. c
37. b
**Multiple Choice**

1. Autotrophs differ from heterotrophs because they
   A utilize oxygen to burn food.
   B do not require oxygen to live.
   C make carbon dioxide as a product of using food.
   D make their own food from carbon dioxide and water.

2. The principal pigment in plants is
   A chlorophyll.  C ATP.
   B oxygen.  D NADPH.

3. Which of the following is NOT produced in the light-dependent reactions of photosynthesis?
   A NADPH
   B sugars
   C hydrogen ions
   D ATP

4. Which of the following correctly summarizes the process of photosynthesis?
   A $\text{H}_2\text{O} + \text{CO}_2 \xrightarrow{\text{light}} \text{sugars} + \text{O}_2$
   B $\text{sugars} + \text{O}_2 \xrightarrow{\text{light}} \text{H}_2\text{O} + \text{CO}_2$
   C $\text{H}_2\text{O} + \text{O}_2 \xrightarrow{\text{light}} \text{sugars} + \text{CO}_2$
   D $\text{sugars} + \text{CO}_2 \xrightarrow{\text{light}} \text{H}_2\text{O} + \text{O}_2$

5. The color of light that is LEAST useful to a plant during photosynthesis is
   A red.  C green.
   B blue.  D violet.

6. The first step in photosynthesis is the
   A synthesis of water.
   B production of oxygen.
   C breakdown of carbon dioxide.
   D absorption of light energy.

7. In a typical plant, all of the following factors are necessary for photosynthesis EXCEPT
   A chlorophyll.
   B light.
   C oxygen.
   D water.

---

**Open-Ended Response**

11. Describe how high-energy electrons are ultimately responsible for driving the photosynthetic reactions.

---

**Answers**

1. D
2. A
3. B
4. A
5. C
6. D
7. C
8. D
9. B
10. D

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**Test-Taking Tip**

**INTERPRET VISUALS**

When a paragraph and related questions accompany a visual, tell students to first carefully read the paragraph and all the labels on the visual. The accompanying paragraph often will put the visual in some context, as well as provide a description or explanation of the visual itself. Reading the labels carefully lets the reader know what specific structures, events, or measurements are shown on the visual. After reading the paragraph and labels, look for any trends or comparisons that the visual presents. After taking these steps to interpret the visual, read and answer the questions.
Connect to the Big Idea

Use the micrograph of the mitochondria to help students start thinking about the concepts of cellular respiration and fermentation. First, activate prior knowledge by asking them if they know what mitochondria are and what their function is. (cellular organelles that convert the chemical energy stored in food into chemical compounds that cells can use)

Now ask students what links the cereal they had for breakfast with the mitochondria in the micrograph. (energy) Point out that food, like this morning’s cereal, contains molecules that the mitochondria can use to make energy available to cells. Then, ask why cells need energy. (to carry out cell activities) Ask students to anticipate the answer to the question, How do organisms obtain energy?

Have students read over the Chapter Mystery and predict how sperm whales can stay active for so long on only one breath. To make their predictions, suggest students think about how cells obtain and release the energy whales need to dive. Use their predictions to help them start connecting the Chapter Mystery to the Big Idea of the Cellular Basis of Life.

Have students preview the chapter vocabulary terms using the Flash Cards.

Understanding by Design

A cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive. Students explore this Enduring Understanding in Chapter 9 by examining the processes of cellular respiration and fermentation. As shown in the graphic organizer at the right, the Big Idea, Essential Question, and lesson-level Guiding Questions help frame their exploration.

PERFORMANCE GOALS

In Chapter 9, students will learn how cellular respiration and fermentation provide organisms with the energy they need to survive. Students will show this understanding by interpreting multiple, detailed figures. They will also practice their data analysis skills by collecting and interpreting data on the byproducts of cellular respiration. At the end of the chapter, students will transfer their knowledge by keeping an exercise journal and relating the entries to cellular respiration and fermentation.
DIVING WITHOUT A BREATH

Everyone is familiar with the sensation of being “out of breath.” Just a few minutes of vigorous exercise can have humans huffing and puffing for air. But what if you couldn’t get air? What if you were asked to hold your breath and exercise? Before too long, you’d pass out due to a lack of oxygen. This may seem like a silly thought experiment, but there are animals that exercise without breathing and without passing out all the time—whales. Unlike most animals that live their entire lives in water, whales still rely on oxygen obtained from air when they surface. Amazingly, sperm whales routinely stay underwater for 45 minutes or more when diving. Some scientists suspect that they can stay underwater for 90 minutes! How is that possible? Diving takes a lot of energy. How do whales stay active for so long on only one breath? As you read this chapter, look for clues. Then, solve the mystery.

UNTAimed SCIENCE

Dive below the ocean surface to explore how marine mammals can survive on a single breath for as long as they do.
Getting Started

Objectives

9.1.1 Explain where organisms get the energy they need for life processes.
9.1.2 Define cellular respiration.
9.1.3 Compare photosynthesis and cellular respiration.

Student Resources

Study Workbooks A and B, 9.1 Worksheets
Spanish Study Workbook, 9.1 Worksheets
Lab Manual B, 9.1 Data Analysis Worksheet

Activate Prior Knowledge

Write the term cellular respiration on the board. Then, make a T-Chart below it. Label one column Facts and the other Questions. Have each student come up to the board and write either a fact they know or a question they have about cellular respiration. Discuss the T-Chart as a class. Answer any questions that students will need to know before reading the lesson.

Study Wkbs A/B, Appendix S30, T-Chart.

Transparencies, GO15.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

I, V

CONTENT

B.3, C.1.a, C.1.b, C.5.a, C.5.c, C.5.d

INQUIRY

A.1.c, A.2.a, A.2.d

Cellular Respiration: An Overview

Key Questions

Where do organisms get energy?
What is cellular respiration?
What is the relationship between photosynthesis and cellular respiration?

Vocabulary

calorie • cellular respiration • aerobic • anaerobic

Taking Notes

Preview Visuals Before you read, study Figure 9–2 on page 252. Make a list of questions that you have about the diagram. As you read, write down the answers to the questions.

BUILD Vocabulary

PREFIXES The prefix macro- means “large” or “elongated.” Macromolecules are made up of many smaller molecular subunits. Carbohydrates, proteins, and lipids are important macromolecules found in living things.

THINK ABOUT IT

When you are hungry, how do you feel? If you are like most people, you might feel sluggish, a little dizzy, and—above all—weak. Weakness is a feeling triggered by a lack of energy. You feel weak when you are hungry because food serves as a source of energy. Weakness is your body’s way of telling you that your energy supplies are low. But how does food get converted into a usable form of energy? Car engines have to burn gasoline in order to release its energy. Do our bodies burn food the way a car burns gasoline, or is there something more to it?

Chemical Energy and Food

Where do organisms get energy?

Food provides living things with the chemical building blocks they need to grow and reproduce. Recall that some organisms, such as plants, are autotrophs, meaning that they make their own food through photosynthesis. Other organisms are heterotrophs, meaning that they rely on other organisms for food. For all organisms, food molecules contain chemical energy that is released when their chemical bonds are broken.

Organisms get the energy they need from food.

How much energy is actually present in food? Quite a lot, although it varies with the type of food. Energy stored in food is expressed in units of calories. A calorie is the amount of energy needed to raise the temperature of 1 gram of water 1 degree Celsius. The Calorie (capital C) that is used on food labels is a kilocalorie, or 1000 calories. Cells can use all sorts of molecules for food, including fats, proteins, and carbohydrates. The energy stored in each of these macromolecules varies because their chemical structures, and therefore their energy-storing bonds, differ. For example, 1 gram of the sugar glucose releases 3811 calories of heat energy when it is burned. By contrast, 1 gram of the triglyceride fats found in beef releases 8993 calories of heat energy when its bonds are broken. In general, carbohydrates and proteins contain approximately 4000 calories (4 Calories) of energy per gram, while fats contain approximately 9000 calories (9 Calories) per gram.

Cells, of course, don’t simply burn food and release energy as heat. Instead, they break down food molecules gradually, capturing a little bit of chemical energy at key steps. This enables cells to use the energy stored in the chemical bonds of foods like glucose to produce compounds such as ATP that directly power the activities of the cell.
Overview of Cellular Respiration

What is cellular respiration?

If oxygen is available, organisms can obtain energy from food by a process called cellular respiration. Cellular respiration is the process that releases energy from food in the presence of oxygen. Although cellular respiration involves dozens of separate reactions, an overall chemical summary of the process is remarkably simple:

In Symbols:

\[ 6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + \text{Energy} \]

In Words:

Oxygen + Glucose \rightarrow Carbon dioxide + Water + Energy

As you can see, cellular respiration requires oxygen and a food molecule such as glucose, and it gives off carbon dioxide, water, and energy. Do not be misled, however, by the simplicity of this equation. If cellular respiration took place in just one step, all of the energy from glucose would be released at once, and most of it would be lost in the forms of light and heat. Clearly, a living cell has to control that energy. It can’t simply start a fire—the cell has to release the explosive chemical energy in food molecules a little bit at a time. The cell needs to find a way to trap those little bits of energy by using them to make ATP.

In Your Notebook: Do plants undergo cellular respiration? What organelle(s) do they have that helps you determine the answer?

Teach

Lead a Discussion

Make sure students understand the overall chemical summary for cellular respiration. Reinforce that the bolded reactions shown are simplifications, or summations, of many sub-reactions. Have students verify that the reaction shown is balanced by counting the molecules of each element on the right and left sides of the reaction.

Differentiated Instruction

Struggling Students

Write the word form of the cellular respiration summary on the board. Then, read it aloud, pointing to each word and reaction symbol as you read. For example, you might say, “oxygen and glucose are converted into carbon dioxide and water and energy.” As you say oxygen, point to the word; as you say and, point to the plus sign. Then, write the symbol form of the summary below it. Draw lines from each chemical formula to its corresponding name in the word form of the summary.

Focus on ELL:

Build Background

BEGINNING AND INTERMEDIATE SPEAKERS

Distribute copies of a BKWL Chart to your students. Then, show students a short animation, video, or several drawings of the process of cellular respiration. Have them take notes on the visuals in the build background column. Write the words obtain, release, extract, respiration, and energy on the board. Have them copy the words and define each in the build background column. Then, have students fill out the K and W columns of the chart. As students read the lesson, have them fill in the L column.

Study Wkbs A/B, Appendix S27, BKWL Chart. Transparencies, GO12.

Answers

In Your Notebook: Yes; they contain mitochondria.

Purposes

Students will examine and interpret data to find how the energy content in foods varies.

Planning

Have a few of the foods listed in the table on hand, and display them for students before they do the activity. Ask students to predict which of the foods contain the most Calories, and have them explain their reasoning.

Answers

1. Eggs have the most protein; chocolate has the most carbohydrates; chocolate has the most fat.
2. There are approximately 9 more Calories in 2 slices of bacon than in 3 slices of roast turkey. The primary difference is that the bacon contains so much more fat than the turkey.
3. A little over 44 minutes
Teach continued

Use Visuals

Use Figure 9–2 to talk about the overall process of cellular respiration. Start by helping students make the connection between this visual and the chemical summary equations from the previous page. Point out where and how glucose and oxygen are used during the process and that water, carbon dioxide, and energy are released. Make sure students understand that cellular respiration can be divided into three basic stages. Tell them that they will learn more detailed information about each of these stages in later lessons.

DIFFERENTIATED INSTRUCTION

Struggling Students Have students read the section, Stages of Cellular Respiration, in the text and look carefully at Figure 9–2. As a class, discuss the first pictured stage, glycolysis. Then, have students write a one-sentence summary of the discussion. For example, students might write, “During glycolysis, glucose is broken down into pyruvic acid and energy is released.” Then, discuss and summarize each of the next two stages.

Address Misconceptions

Cellular Respiration v. Respiration Some of your students may have difficulty distinguishing between the concepts of cellular respiration and respiration as breathing. Have students read the first paragraph of the Oxygen and Energy section, research the connection between the two processes, and make a poster for the classroom wall that graphically shows the relationship.

Answers

FIGURE 9–2 the Krebs cycle and the electron transport chain

IN YOUR NOTEBOOK Flowcharts should accurately show the connections between glycolysis, the Krebs cycle, and the electron transport chain.

Check for Understanding

INDEX CARD SUMMARIES

Give students each an index card, and ask them to write one important idea about cellular respiration that they understand on the front of the card. Then, have them write something about cellular respiration that they don’t understand on the back of the card in the form of a question.

ADJUST INSTRUCTION

Read over students’ cards to get a sense of which concepts they understand and which they are struggling with. If a question will be answered by reading the rest of the chapter, use that card when the time comes to emphasize a concept. If the answer to a question is necessary to move forward, review the topic as a class to allow students to hear the concept discussed in different ways.

Stages of Cellular Respiration Cellular respiration captures the energy from food in three main stages—glycolysis, the Krebs cycle, and the electron transport chain. Although cells can use just about any food molecule for energy, we will concentrate on just one as an example—the simple sugar glucose. Glucose first enters a chemical pathway known as glycolysis (gly kahl ih sis). Only a small amount of energy is captured to produce ATP during this stage. In fact, at the end of glycolysis, about 90 percent of the chemical energy that was available in glucose is still unused, locked in chemical bonds of a molecule called pyruvic (py roo vik) acid.

How does the cell extract the rest of that energy? First, pyruvic acid enters the second stage of cellular respiration, the Krebs cycle, where a little more energy is generated. The bulk of the energy, however, comes from the final stage of cellular respiration, the electron transport chain. This stage requires reactants from the other two stages of the process, as shown by dashed lines in Figure 9–2. How does the electron transport chain extract so much energy from these reactants? It uses one of the world’s most powerful electron acceptors—oxygen.

Oxygen and Energy Oxygen is required at the very end of the electron transport chain. Any time a cell’s demand for energy increases, its use of oxygen increases, too. As you know, the word respiration is often used as a synonym for breathing. This is why we have used the term cellular respiration to refer to energy-releasing pathways within the cell. The double meaning of respiration points out a crucial connection between cells and organisms: Most of the energy-releasing pathways within cells require oxygen, and that is the reason we need to breathe, to respire.

Pathways of cellular respiration that require oxygen are said to be aerobic (“in air”). The Krebs cycle and electron transport chain are both aerobic processes. Even though the Krebs cycle does not directly require oxygen, it is classified as an aerobic process because it cannot run without the oxygen-requiring electron transport chain. Glycolysis, however, does not directly require oxygen, nor does it rely on an oxygen-requiring process to run. Glycolysis is therefore said to be anaerobic (“without air”). Even though glycolysis is anaerobic, it is considered part of cellular respiration because its final products are key reactants for the aerobic stages.

Recall that mitochondria are structures in the cell that convert chemical energy stored in food to usable energy for the cell. Glycolysis actually occurs in the cytoplasm of a cell, but the Krebs cycle and electron transport chain, which generate the majority of ATP during cellular respiration, take place inside the mitochondria. If oxygen is not present, another anaerobic pathway, known as fermentation, makes it possible for the cell to keep glycolysis running, generating ATP to power cellular activity. You will learn more about fermentation later in this chapter.

FIGURE 9–2 The Stages of Cellular Respiration There are three stages to cellular respiration: glycolysis, the Krebs cycle, and the electron transport chain. Interpret Visuals Which stage(s) of cellular respiration occur in the mitochondria?
Comparing Photosynthesis and Cellular Respiration

What is the relationship between photosynthesis and cellular respiration?

If nearly all organisms break down food by the process of cellular respiration, why doesn’t Earth run out of oxygen? Where does all of the carbon dioxide waste product go? How does the chemical energy stored in food get replaced? As it happens, cellular respiration is balanced by another process: photosynthesis. The energy in photosynthesis and cellular respiration flows in opposite directions. Look at Figure 9–3 and think of the chemical energy in carbohydrates as money in the Earth’s savings account. Photosynthesis is the process that “deposits” energy. Cellular respiration is the process that “withdraws” energy. As you might expect, the equations for photosynthesis and cellular respiration are the reverse of each other.

On a global level, photosynthesis and cellular respiration are also opposites. Photosynthesis removes carbon dioxide from the atmosphere, and cellular respiration puts it back. Photosynthesis releases oxygen into the atmosphere, and cellular respiration uses that oxygen to release energy from food. The release of energy by cellular respiration takes place in nearly all life: plants, animals, fungi, protists, and most bacteria. Energy capture by photosynthesis, however, occurs only in plants, algae, and some bacteria.

Assess and RemEDIATE

EVALUATE UNDERSTANDING

Have pairs of students use Figure 9–3 to help them summarize the content of the lesson. For example, ask them to explain why both the rabbit and the plant are producing ATP and heat. Listen to their discussions to help you evaluate their grasp of lesson concepts. Then, have them complete the 9.1 Assessment.

REMEDIATION SUGGESTION

Less Proficient Readers If students have trouble understanding Question 2b, suggest they use the Glossary at the back of this text to review the meaning of the term homeostasis.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. Food provides organisms with the energy they need to carry out life processes such as growth and reproduction.

1b. The amount of energy stored in macromolecules varies because their chemical structures, and therefore the energy contained in their chemical bonds, differ.

2a. \( 6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + \text{Energy} \)

2b. The process of cellular respiration provides the energy a cell needs to carry out basic cell processes, which, in turn, control the cell’s internal conditions.

3a. Photosynthesis “deposits” energy, uses carbon dioxide and water, and produces oxygen and glucose. By contrast, cellular respiration “withdraws” energy, uses oxygen and glucose, and produces carbon dioxide and water.

3b. Chemical energy is stored in the chemical bonds of glucose, just as money is stored in a savings account.

BUILD VOCABULARY

4. Sample answer: a process that involves the breaking down of a sweet substance
Getting Started

Objectives

9.2.1 Describe what happens during glycolysis.
9.2.2 Describe what happens during the Krebs cycle.
9.2.3 Explain how high-energy electrons are used by the electron transport chain.
9.2.4 Identify how much ATP cellular respiration generates.

Student Resources

Study Workbooks A and B, 9.2 Worksheets
Spanish Study Workbook, 9.2 Worksheets

For corresponding lesson in the Foundation Edition, see pages 216–222.

Activate Prior Knowledge

Ask students to think about how they get to school every day. Have them break this process into several stages. For example, they might describe getting ready to leave home, taking the bus, and walking into school. Then, have them discuss with a partner why it makes sense that cellular respiration provides the energy and basic structure organisms need to survive.

For corresponding lesson in the Foundation Edition, see pages 216–222.

The Process of Cellular Respiration

Glycolysis

What happens during the process of glycolysis?
The first set of reactions in cellular respiration is known as glycolysis, a word that literally means “sugar-breaking.” Glycolysis involves many chemical steps that transform glucose. The end result is 2 molecules of a 3-carbon molecule called pyruvic acid.

During glycolysis, 1 molecule of glucose, a 6-carbon compound, is transformed into 2 molecules of pyruvic acid, a 3-carbon compound. As the bonds in glucose are broken and rearranged, energy is released. The process of glycolysis can be seen in Figure 9–4.

ATP Production

Even though glycolysis is an energy-releasing process, the cell needs to put in a little energy to get things going. At the pathway’s beginning, 2 ATP molecules are used up. Earlier in this chapter, photosynthesis and respiration were compared, respectively, to a deposit to and a withdrawal from a savings account. Similarly, the 2 ATP molecules used at the onset of glycolysis are like an investment that pays back interest. In order to earn interest from a bank, first you have to put money into an account. Although the cell puts 2 ATP molecules into its “account” to get glycolysis going, glycolysis produces 4 ATP molecules. This gives the cell a net gain of 2 ATP molecules for each molecule of glucose that enters glycolysis.

THINK ABOUT IT

Food burns! It’s true, of course, that many common foods (think of apples, bananas, and ground beef) have too much water in them to actually light with a match. However, foods with little water, including sugar and cooking oil, will indeed burn. In fact, flour, which contains both carbohydrates and protein, is so flammable that it has caused several explosions, including the one seen here at London’s City Flour Mills in 1872 (which is why you’re not supposed to store flour above a stove). So, plenty of energy is available in food, but how does a living cell extract that energy without setting a fire or blowing things up?
glycolysis, molecules are passed to the carrier NAD+ to produce NADH. NADH carries these electrons to the electron transport chain. Four high-energy electrons are passed to the carrier NAD+ to produce NADH. NADH carries these electrons to the electron transport chain. One of the reactions of glycolysis removes 4 electrons, now in a high-energy state, and passes them to an electron carrier called NAD+, or nicotinamide adenine dinucleotide. Like NADP+ in photosynthesis, each NAD+ molecule accepts a pair of high-energy electrons. This molecule, now known as NADH, holds the electrons until they can be transferred to other molecules. As you will see, in the presence of oxygen, these high-energy electrons can be used to produce even more ATP molecules.

The Advantages of Glycolysis In the process of glycolysis, 4 ATP molecules are synthesized from 4 ADP molecules. Given that 2 ATP molecules are used to start the process, there is a net gain of just 2 ATP molecules. Although the energy yield from glycolysis is small, the process is so fast that cells can produce thousands of ATP molecules in just a few milliseconds. The speed of glycolysis can be a big advantage when the energy demands of a cell suddenly increase. Besides speed, another advantage of glycolysis is that the process itself does not require oxygen. This means that glycolysis can quickly supply chemical energy to cells when oxygen is not available. When oxygen is available, however, the pyruvic acid and NADH “outputs” generated during glycolysis become the “inputs” for the other processes of cellular respiration.

In Your Notebook In your own words, describe the advantages of glycolysis to the cell in terms of energy production.

Glycolysis

FIGURE 9–4 Glycolysis is the first stage of cellular respiration. During glycolysis, glucose is broken down into 2 molecules of pyruvic acid. ATP and NADH are produced as part of the process. 

1. **Interpret Visuals** How many carbon atoms are there in glucose? How many carbon atoms are in each molecule of pyruvic acid?

**NADH Production**

Four high-energy electrons are passed to the carrier NAD+ to produce NADH. NADH carries these electrons to the electron transport chain.

**ATP Production**

Two ATP molecules are “invested” to get the process of glycolysis going. Overall, 4 ATP molecules are produced, for a net gain of 2 ATP per molecule of glucose.

**To Electron Transport Chain**

**To Krebs Cycle**

**Fast Facts**

**BEGINNING WITH GLUCOSE**

Why do biologists pay so much attention to glucose? It’s because most other food molecules are broken down to release energy in much the same way. Proteins are broken down into individual amino acids, which are converted to compounds that can enter either glycolysis or the Krebs cycle. Carbohydrates are generally broken into simple sugars and then converted into glucose. Lipids are broken down into fatty acids and glycerol. These compounds enter the mitochondria where special enzymes cut them up, two carbon atoms at a time, to produce acetyl-CoA, which then enters the Krebs cycle. This means that literally any food can provide the chemical energy for cellular respiration—the body is a furnace that can run on any fuel.

Teach

**ZOOMING IN**

Suggest students look carefully at Figure 9–4. Then, use the figure to start a discussion on glycolysis. Call on students at random to answer questions about what they observe.

**Ask** What do the six dark balls at the top of the figure represent? (the six carbon atoms in a molecule of glucose)

**Ask** What does it mean to “invest” a molecule of ATP? (The energy stored in ATP is released and used to help start the process of glycolysis.)

**Ask** What are the products of glycolysis? (2 NADH molecules, 2 pyruvic acid molecules, and 4 ATP molecules)

**Ask** Where do these products go? (The NADH goes to the electron transport chain, the pyruvic acid goes to the Krebs cycle, and the ATP gets used by cells.)

**DIFFERENTIATED INSTRUCTION**

**ESL Special Needs** Have students work in pairs to make a model of glycolysis. Have them use pop beads to represent carbon molecules, and different-size paper clips to model ATP/ADP and NAD+/NADH. Have pairs discuss the process as they model it.

**BUILD Vocabulary**

**ACADEMIC WORDS** The verb synthesize means “to bring together as a whole.” Therefore, a molecule of ATP is synthesized when a phosphate group combines with the molecule ADP, forming a high-energy bond.

**BIOLOGY.COM** For an overview of the processes covered in this chapter, suggest students watch InterActive Art: Cellular Respiration and Fermentation.

Address Misconceptions

**Energy** Some students may think that energy is somehow created during glycolysis and the other stages of cellular respiration. Remind students that energy cannot be created or destroyed. Reinforce the fact that the energy used in glycolysis to make ATP is stored in the chemical bonds of glucose. Suggest students investigate how energy is stored as potential energy in chemical bonds and make a presentation to the class of what they learn.

**Answers**

**FIGURE 9–4** 6 carbon atoms in glucose; 3 carbon atoms in each molecule of pyruvic acid

**IN YOUR NOTEBOOK** Students’ descriptions should mention that there is a net gain of 2 ATP molecules, that the process is fast, and that it can supply energy to the cell when oxygen is not available.


LESSON 9.2

Teach continued

Connect to Chemistry

An understanding of the three stages of cellular respiration depends on some knowledge of basic chemistry. Before students study the Krebs cycle, point out that the cycle is a series of chemical reactions mainly involving carbon compounds. Explain that the element carbon has a remarkable ability to easily combine with both itself and other atoms, and the result is a tremendous number of carbon compounds in living things. Point out that following the changing carbon compounds is key to understanding the Krebs cycle.

DIFFERENTIATED INSTRUCTION

Struggling Students Some students may have a difficult time understanding how ATP stores energy. Tell students that a common analogy used for ATP is that its three phosphates are like a loaded spring. Losing one of the phosphates—the source of energy for a cell—is like relaxing the spring. Adding a phosphate to a molecule of ADP is like loading, or compressing, the spring again.

Less Proficient Readers Struggling readers may stumble on the names of the compounds pyruvic acid, acetyl-CoA, and citric acid. Before students read, preview these terms by writing the names on the board and saying each name aloud. Have students repeat the words so they become comfortable reading and pronouncing them.

To help students answer the question, explain that tolerance means “able to withstand the effects of something without showing the usual unfavorable effects.” Point out that some people, for example, are able to tolerate colder temperatures than others. Students can go online to Biology.com to gather their evidence.

Answers

IN YOUR NOTEBOOK The electron carriers involved in the Krebs cycle are NAD⁺ and FAD. After they accept electrons, NAD⁺ becomes NADH and FAD becomes FADH₂.

The Krebs Cycle

What happens during the Krebs cycle?

In the presence of oxygen, pyruvic acid produced in glycolysis passes to the second stage of cellular respiration, the Krebs cycle. The Krebs cycle is named after Hans Krebs, the British biochemist who demonstrated its existence in 1937. During the Krebs cycle, pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions. Because citric acid is the first compound formed in this series of reactions, the Krebs cycle is also known as the citric acid cycle.

Citric Acid Production The Krebs cycle begins when pyruvic acid produced by glycolysis passes through the two membranes of the mitochondrion and into the matrix. The matrix is the innermost compartment of the mitochondrial and the site of the Krebs cycle reactions. Once inside the matrix, 1 carbon atom from pyruvic acid becomes part of a molecule of carbon dioxide, which is eventually released into the air. The other 2 carbon atoms from pyruvic acid rearrange and form acetic acid, which is joined to a compound called coenzyme A. The resulting molecule is called acetyl-CoA. (The acetyl part of acetyl-CoA is made up of 2 carbon atoms, 1 oxygen atom, and 3 hydrogen atoms.) As the Krebs cycle begins, acetyl-CoA adds the 2-carbon acetyl group to a 4-carbon molecule already present in the cycle, producing a 6-carbon molecule called citric acid.

Energy Extraction As the cycle continues, citric acid is broken down into a 4-carbon molecule, more carbon dioxide is released, and electrons are transferred to energy carriers. Follow the reactions in Figure 9-5 and you will see how this happens. First, look at the 6 carbon atoms in citric acid. One is removed, and then another, releasing 2 molecules of carbon dioxide and leaving a 4-carbon molecule. Why is the Krebs cycle a “cycle”? Because the 4-carbon molecule produced in the last step is the same molecule that accepts the acetyl-CoA in the first step. The molecule needed to start the reactions of the cycle is remade with every “turn.”

Next, look for ATP. For each turn of the cycle, a molecule of ADP is converted to a molecule of ATP. Recall that glycolysis produces 2 molecules of pyruvic acid from 1 molecule of glucose. So, each starting molecule of glucose results in two complete turns of the Krebs cycle and, therefore, 2 ATP molecules. Finally, look at the electron carriers, NAD⁺ and FAD (flavine adenine dinucleotide). At five places, electron carriers accept a pair of high-energy electrons, changing NAD⁺ to NADH and FAD to FADH₂. FAD and FADH₂ are molecules similar to NAD⁺ and NADH, respectively.

What happens to each of these Krebs cycle products—carbon dioxide, ATP, and electron carriers? Carbon dioxide is not useful to the cell and is expelled every time you exhale. The ATP molecules are very useful and become immediately available to power cellular activities. As for the carrier molecules like NADH, in the presence of oxygen, the electrons they hold are used to generate huge amounts of ATP.

In Your Notebook List the electron carriers involved in the Krebs cycle. Include their names before and after they accept the electrons.

UBD Check for Understanding

ORAL QUESTIONING

Use the following prompts to gauge student understanding of the Krebs cycle:

• Why does glycolysis have to occur before the Krebs cycle can occur?
• For each turn of the Krebs cycle, what is produced that can immediately be used to power cell activities?
• How does the cell use the NADH and FADH₂ produced in the Krebs cycle?

ADJUST INSTRUCTION

Evaluate students’ answers to get a sense of which concepts they understand and which concepts they are having trouble with. Because understanding the Krebs cycle is essential to understanding the whole process of cellular respiration, review difficult concepts as a class so students can hear events described in different ways.
**Biology In-Depth**

**ATP—OR GTP?**

In the description and illustration of the Krebs cycle above, each turn of the cycle is said to produce 1 molecule of ATP. Designating ATP as a product of the Krebs cycle is done for the sake of simplicity. The triphosphate compound actually produced in the Krebs cycle is GTP (guanosine triphosphate) from GDP—not ATP from ADP. The amount of energy trapped in GTP is identical to that in ATP. When pools of ATP are low in the cell, the third phosphate of GTP is efficiently transferred, with the help of an enzyme, to ADP to produce ATP. This process provides more ATP for the cell to use and also leaves behind GDP, which can then accept another phosphate in the Krebs cycle.

**Answers**

**FIGURE 9–5** Both the NADH and FADH₂ molecules feed into the last step of cellular respiration, the electron transport chain.
Build Reading Skills

Explain that one way to organize information in a long reading passage is to create a graphic representation of the information. In this case, the reading describes a process—electron transport and ATP synthesis—that can be well represented by a flowchart. Ask students to help you construct a Flowchart of the process on the board. Begin with this first step: NADH and FADH$_2$, from glycolysis and the Krebs cycle, enter the electron transport chain. Ask students to suggest the next step as well as further steps in the process. The last step should be production of ATP as hydrogen ions pass through ATP synthase.


DIFFERENTIATED INSTRUCTION

Less Proficient Readers In simplified language, paraphrase the most important concepts about Electron Transport and ATP Production. For example, write on the board:

Electron Transport:

- NADH and FADH$_2$ pass electrons to the electron transport chain.
- Electrons are then passed from one carrier to the next.
- Each time electrons are passed, hydrogen moves across the membrane.
- Hydrogen ions build up in the intermembrane space. This space becomes positively charged.
- Oxygen is the final electron acceptor.

Create a similar bulleted list for ATP production. Keep these lists on the board for students to refer to as they work through Figure 9–6.

Quick Facts

ATP PRODUCTION IN THE ELECTRON TRANSPORT CHAIN

To produce 3 molecules of ATP, each pair of high-energy electrons must move down the full length of the electron transport chain. NADH molecules “drop off” their electrons at the start of the chain, and therefore these electrons power the production of about 3 molecules of ATP each. The electron carrier FADH$_2$, however, enters lower on the chain, and its electrons have a bit less energy. As a result, the electrons of each FADH$_2$ molecule provide only enough energy for the production of about 2 molecules of ATP.
Help orient students as they interpret Figure 9–6. Start by pointing out the electron carriers NADH from glycolysis and the Krebs cycle and FADH$_2$ from the Krebs cycle. Have students trace how these carriers move through the matrix to the first protein in the electron transport chain. Then, have them follow the electrons through the chain to oxygen.

**Ask** How do electron carriers use the energy generated by passing the electrons down the electron transport chain? (to transport hydrogen ions across the inner mitochondrial membrane)

Then, direct students’ attention to the ATP synthase molecule shown at the lower right of the figure.

**Ask** What causes the production of ATP from ADP? (As H$^+$ ions rush through ATP synthase, the base of the synthase rotates, generating ATP from ADP)

**Ask** What causes the H$^+$ ions to rush through the ATP synthase? (the concentration gradient of H$^+$ across the inner mitochondrial membrane, which it cannot directly cross)

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** Many students may find interpreting the figure difficult. To help these students, redraw the figure on the board in a simplified form. Start by sketching the electron transport chain. Draw a line to represent the membrane and five circles to represent the electron carrier proteins in the membrane. Then, draw an NADH molecule approaching the chain. Have students direct you as you draw the electrons from NADH entering the chain. Show how electrons move down the chain, continuing until they reach oxygen. Also, show how hydrogen ions move through the carrier proteins from the matrix into the intermembrane space.

**Ask** Which contains more hydrogen ions than it did before the process started, the intermembrane space or the matrix? (the intermembrane space)

**Ask** Which side has less? (the matrix)

Then, extend the line for the membrane and sketch an ATP synthase. Show an ion moving back through the synthase, producing ATP.
Lead a Discussion

Explain to students that the number of ATP molecules produced by a molecule of glucose is variable and difficult to determine exactly. Point out that the actual number is likely in the range of 30–42 ATPs per glucose. Mention that a total of 36 ATPs, though, is reasonable since it assumes 2 ATPs per FADH₂ and 3 ATPs per NADH (with approximately 2 ATPs lost due to the cost of transporting NADH produced in the cytoplasm into the mitochondria for oxidation).

Assess and Remediate

EVALUATE UNDERSTANDING

Call on students at random to describe the main events in each stage of cellular respiration. Then, have students complete the 9.2 Assessment.

REMEDIATION SUGGESTION

L Struggling Students: If students cannot identify the function of NADP⁺ in Question 1b, advise them to look back to Lesson 8.3, where they learned about the electron carriers involved in photosynthesis.

Answers

FIGURE 9–7 18 times more energy

Assessment Answers

1a. 2 molecules of pyruvic acid, 2 molecules of NADH, and a net gain of 2 ATP molecules per glucose. Mention that a total of 36 ATPs, though, is reasonable since it assumes 2 ATPs per FADH₂ and 3 ATPs per NADH (with approximately 2 ATPs lost due to the cost of transporting NADH produced in the cytoplasm into the mitochondria for oxidation).

3a. to power the “pumping” of H⁺ ions against a concentration gradient from the matrix to the intermembrane space

3b. The charge differences force protons through ATP synthase, which powers the conversion of ADP to ATP.

4a. about 36 molecules of ATP per molecule of glucose

4b. It can “burn” many different types of fuels, not just glucose. Also, a cell releases heat energy through the breakdown of glucose that heats the organism, just as a furnace releases energy to heat a building.

5. The body uses the ATP generated by cellular respiration to carry out basic life processes such as reproduction, growth, and development.
ATP is the chemical compound that gives muscles the energy to contract, but the amount of ATP in most muscle cells is only enough for a few seconds of activity. Muscle cells have a chemical trick, however, that enables them to sustain maximum effort for several more seconds. They attach phosphate groups to a compound called creatine. As they contract, the cells quickly transfer phosphate from creatine to ADP, producing enough ATP to keep working. The creatine phosphate in skeletal muscles effectively doubles or triples the amount of ATP available for intense exercise.

If a little creatine is good, then more creatine would be even better, right? That's what many athletes think and that's why they take creatine supplements. Some studies do suggest that creatine may increase the body's capacity for strong, short-term muscle contractions. As a reason to regulate the use of creatine, however, critics point to potentially serious side effects—such as liver and kidney damage—when creatine is overused.

Because creatine occurs naturally in the body and in foods, testing for creatine use is nearly impossible; so, creatine is not banned in major sports leagues. However, due to a lack of long-term studies, the NCAA prohibits coaches from giving creatine to college athletes. Some schools argue that creatine should be banned altogether.

### The Viewpoints

**Creatine Supplements Should Not Be Regulated**

Taken in recommended doses, creatine helps build muscle strength and performance. Creatine supplements may help athletes train longer and build strength. No serious side effects have been reported in people who follow the instructions on container labels. Of course, anything can be harmful when abused, but creatine should not be treated any differently from other substances such as caffeine or sugar.

**Creatine Supplements Should Be Regulated**

Scientists know that creatine can cause severe health problems when abused. But even when used properly, creatine is known to cause some problems, such as dehydration and stomach upset. There have been no adequate studies on creatine use by people younger than 18, and there are no good studies of its long-term effects. For these reasons, creatine supplements should be regulated like cigarettes and alcohol—no one under the age of 18 should be allowed to buy them, and schools should have the right to regulate or prohibit their use by athletes.

### Research and Decide

1. **Analyze the Viewpoints**
   Learn more about this issue by consulting library or Internet resources. Then, list the key arguments of the proponents and critics of creatine use.

2. **Form an Opinion**
   Should creatine be regulated? Research examples of high schools or colleges that have banned creatine use by athletes. What were the reasons for these decisions? Do you agree with them?

### Quick Facts

**CREATINE**

Creatine is an interesting compound. It is naturally produced in the body, primarily in the kidneys and liver, and then transported through the blood to muscles. Other interesting facts about creatine include:

- Creatine supplements are sold in several forms, including powder, tablets, energy bars, and drinks.
- Creatine supplements are not considered to be medicines, and therefore they are not regulated by the Federal Drug Administration (FDA).
- Creatine supplements first became widely popular among athletes in the 1990s.
- Researchers are investigating whether creatine might be helpful in treating such health conditions as heart failure, Huntington’s disease, and muscular dystrophy.
Getting Started

Objectives

9.3.1 Explain how organisms get energy in the absence of oxygen.

9.3.2 Identify the pathways the body uses to release energy during exercise.

Student Resources

Study Workbooks A and B, 9.3 Worksheets
Spanish Study Workbook, 9.3 Worksheets
Lab Manual B, 9.3 Hands-On Activity Worksheet


Activate Prior Knowledge

Have students examine a piece of bread from a leavened loaf and an unleavened loaf. Point out that yeast is added to dough to make it rise. Ask students what process they think yeast cells carry out to cause the characteristics of leavened bread.

Answers

IN YOUR NOTEBOOK Students’ table should include that both processes are anaerobic ways to produce NAD⁺ using pyruvic acid and NADH. Alcoholic fermentation produces alcohol and CO₂; lactic acid fermentation produces lactic acid.

BUILD Vocabulary

RELATED WORD FORMS The noun fermentation and the verb ferment are related word forms. Dough that is beginning to ferment is just starting to undergo the process of fermentation.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

CONTENT

B.3, C.1.a, C.1.b, C.5.c, C.5.d

INQUIRY

A.1.b, A.2.a

Fermentation

THINK ABOUT IT We are air-breathing organisms, and we use oxygen to release chemical energy from the food we eat. But what if oxygen is not around? What happens when you hold your breath and dive under water, or use up oxygen so quickly that you cannot replace it fast enough? Do your cells simply stop working? And, what about microorganisms that live in places where oxygen is not available? Is there a pathway that allows cells to extract energy from food in the absence of oxygen?

Fermentation

How do organisms generate energy when oxygen is not available?

In the absence of oxygen, fermentation releases energy from food molecules by producing ATP.

During fermentation, cells convert NADH to NAD⁺ by passing high-energy electrons back to pyruvic acid. This action converts NADH back into the electron carrier NAD⁺, allowing glycolysis to produce a steady supply of ATP. Fermentation is an anaerobic process that occurs in the cytoplasm of cells. Sometimes, glycolysis and fermentation are together referred to as anaerobic respiration. There are two slightly different forms of the process—alcoholic fermentation and lactic acid fermentation, as seen in Figure 9–8.

In Your Notebook Make a compare/contrast table in which you compare alcoholic fermentation to lactic acid fermentation.

Teach for Understanding

ENDURING UNDERSTANDING A cell is the basic unit of life; the processes that occur at the cellular level provide the energy and basic structure organisms need to survive.

GUIDING QUESTION How do cells release energy from food without oxygen?

EVIDENCE OF UNDERSTANDING Give students this assessment at the end of the lesson to show they understand how cells react when they need to release energy from food without oxygen. Ask each student to write a fictional account of a person running twice around the school’s track at full speed (assume this takes at least 2 minutes). The story should describe how the runner’s body reacts to this strenuous activity, including the runner’s breathing and what happens within the body’s cells as they react to the great demand for energy.
**Check for Understanding**

**ONE-MINUTE RESPONSE**

Give students about a minute to respond to the following question.

- Explain why human cells’ ability to carry out fermentation is important. (Responses should mention that lactic acid fermentation helps us make energy quickly, and continue obtaining energy for activity when oxygen intake is inadequate.)

**ADJUST INSTRUCTION**

If students’ responses are incorrect, lead a short class discussion on the importance of fermentation. Point out that being able to carry out both cellular respiration and fermentation makes humans better adapted for intense activity. Cellular respiration produces more energy, but fermentation allows humans to continue producing energy even when oxygen is not present in adequate amounts.

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**Teach**

**Use Visuals**

Point out to students that, while the figure shows both alcoholic and lactic acid fermentation, these processes do not normally occur at the same time in an organism. Most organisms carry out either one or the other. Explain that the figure shows pyruvic acid from glycolysis entering either alcoholic or lactic acid fermentation, not both at once.

**Ask** Why does a cell need NAD\(^+\) to keep glycolysis going? (The cell needs NAD\(^+\) to accept electrons when glucose is broken down into pyruvic acid.)

**Ask** What is missing from the illustration of fermentation that makes the process anaerobic? (oxygen)

**Ask** Which form of fermentation is carried out by your body? (lactic acid fermentation)

**DIFFERENTIATED INSTRUCTION**

- **Advanced Students** Ask interested students to investigate one of the processes in which fermentation is used in the production of a food or a beverage. Students may use the library or online resources in their research. Ask each student to prepare a written report on the food or beverage chosen and to share the report with the class.

- **ELL Focus on ELL:** Extend Language

**BEGINNING SPEAKERS** Explain that the word fermentation is derived from a Latin word for “yeast.” Point out that this process, then, was named after a microorganism that carries it out. Also, explain that an organism that carries out fermentation is called a fermenter. For example, the text calls humans “lactic acid fermenters.” Divide the word fermentation into word parts. Have students pronounce each part separately and then pronounce the complete word.

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**Answers**

**FIGURE 9-8** Both alcoholic fermentation and lactic acid fermentation have the same two reactants, pyruvic acid and NADH. Both also have one product in common, NAD\(^+\).
Connect to the Real World

**Ask** What do you think the effects of lactic acid buildup in an athlete’s muscles might be? (Sample answers: muscle cramping, soreness, and fatigue) Tell students that, until recently, many people thought that lactic acid buildup was responsible for muscle fatigue and soreness. Point out that researchers have since found that lactic acid can actually be used as a fuel by mitochondria to make energy.

**DIFFERENTIATED INSTRUCTION**

**Advanced Students** Have advanced students write a story about a mountain climber who tries to reach the peak of a mountain in just a few hours. Ask students to include descriptions of the cellular processes used by the mountain climber for the energy needed to reach the peak.

**Ask** How might changes in altitude affect the energy-producing processes in the climber’s body?

Have students use the Data Analysis: Lactic Acid and Athletes to find out more about lactic acid and exercise.

**Answers**

**FIGURE 9–9** ATP that is already in the cell, then ATP produced by lactic acid fermentation

---

**Quick Lab**

**PURPOSE** Students investigate the relationship between exercise and the production of carbon dioxide, a byproduct of cellular respiration.

**MATERIALS** 2 small test tubes, glass-marking pencil, 10-mL graduated cylinder, bromthymol blue solution, straws, clock or watch with second indicator

**SAFETY** Caution students to handle glassware with care. Advise students to wear goggles and lab apron when performing the lab. Read and reinforce the cautionary notes before starting the lab. Have students wash their hands after completing the lab.

**PLANNING** Read the safety information for bromthymol blue before the lab, and warn students not to inhale or swallow the solution. If desired, have students slowly blow through a straw into a test tube that contains just water in order to practice the technique before starting the lab. For special needs students, model the lab in front of the class. Have them perform the role of your partner as you exercise and blow through the straw.

**ANALYZE AND CONCLUDE**

1. Students should find that the solution changed color more rapidly after exercise than before exercise.

2. Cellular respiration produces carbon dioxide. Exercise increases the rate of cellular respiration.
At this point, the runners’ muscle cells are producing most of their ATP by lactic acid fermentation, which can usually supply enough ATP to last about 90 seconds. In a 200- or 300-meter sprint, this may be just enough to reach the finish line.

Fermentation produces lactic acid as a byproduct. When the race is over, the only way to get rid of lactic acid is in a chemical pathway that requires extra oxygen. For that reason, you can think of a quick sprint as building up an oxygen debt that a runner has to repay with plenty of heavy breathing after the race. An intense effort that lasts just 10 or 20 seconds may produce an oxygen debt that requires several minutes of huffing and puffing to clear.

For short, quick bursts of energy, the body uses ATP already in muscles as well as ATP made by lactic acid fermentation.

**Long-Term Energy** What happens if a race is longer? How does your body generate the ATP it needs to run 2 kilometers or more, or to play in a soccer game that lasts more than an hour? For exercise longer than about 90 seconds, cellular respiration is the only way to continue generating a supply of ATP. Cellular respiration releases energy more slowly than fermentation does, which is why even well-conditioned athletes have to pace themselves during a long race or over the course of a game. Your body stores energy in muscle and other tissues in the form of the carbohydrate glycogen. These stores of glycogen are usually enough to last for 15 or 20 minutes of activity. After that, your body begins to break down other stored molecules, including fats, for energy. This is one reason why aerobic forms of exercise such as running, dancing, and swimming are so beneficial for weight control. Some organisms, like the bear in Figure 9–10, count on energy stored in fat to get them through long periods without food.

**FIGURE 9–10 Energy Storage** Hibernating animals like this brown bear in Alaska rely on stored fat for energy when they sleep through the winter. **Predict** How will this bear look different when it wakes up from hibernation?

### Assessment Answers

1a. alcoholic fermentation and lactic acid fermentation

1b. Both forms provide energy to the cell in the absence of oxygen, and both produce NADH. They are different in that alcoholic fermentation produces alcohol and carbon dioxide, while lactic acid fermentation produces lactic acid.

2a. When the race is over, the only way to get rid of lactic acid is through a chemical pathway that requires extra oxygen.

2b. ATP already in muscles, ATP made by lactic acid fermentation, and ATP produced by cellular respiration

3. Answers may vary. Students should demonstrate an understanding that the more alcoholic fermentation that occurs in baking the bread, the more CO₂ will be produced, the more bubbles will occur in the bread, and the lighter the bread will be. Factors that could affect the enzyme-catalyzed fermentation include temperature, amount of yeast added to the dough, the amount of sugar (yeast food) added to the dough, and the pH of the dough. Students should predict how each of these factors would affect the rate of fermentation and then propose a solution based on a prediction.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Comparing Fermentation Rates of Sugars described in Lab Manual A.

Struggling Students: A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Students should wear goggles and a lab apron while performing the lab. They should use care when working with the hot plate. When finished with the activity, students should wash their hands thoroughly.

Look online for Editable Lab Worksheets. For corresponding pre-lab in the Foundation Edition, see page 226.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP III

CONTENT C.1.b, C.5.b

INQUIRY A.1.c, A.2.c

Pre-Lab Answers

BACKGROUND QUESTIONS

a. Without NAD+, glycolysis will not be able to keep going and the production of ATP will stop.

b. Alcohol and carbon dioxide are produced.

c. Sample answer: Simple sugars are the smallest possible carbohydrate molecules. Disaccharides form when two simple sugar molecules join together and form one larger molecule.

d. Sample answer: Fermentation and a detour are both alternate routes, in one case to the release of energy and in the other case to a destination. (In both cases, the alternate route is less efficient.)

PRE-LAB QUESTIONS

1. Sample answer: The layer of vegetable oil will prevent oxygen from reaching the sugar and yeast mixture. In the presence of oxygen, fermentation will not take place.

2. One of the products of fermentation is carbon dioxide, which is a gas. The faster the reaction, the greater the amount of gas in the tube and the greater the pressure will be.

3. Students are likely to choose glucose because they know that the first step in fermentation is the conversion of glucose to pyruvic acid.
Study Guide

**Big Idea: Cellular Basis of Life**
Organisms obtain the energy they need from the breakdown of food molecules by cellular respiration and fermentation.

### 9.1 Cellular Respiration: An Overview
- Organisms get the energy they need from food.
- Cellular respiration is the process that releases energy from food in the presence of oxygen.
- Photosynthesis removes carbon dioxide from the atmosphere, and cellular respiration puts it back. Photosynthesis releases oxygen into the atmosphere, and cellular respiration uses that oxygen to release energy from food.

#### Key Terms
- calorie (250)
- cellular respiration (251)
- aerobic (252)
- anaerobic (252)

### 9.2 The Process of Cellular Respiration
- During glycolysis, 1 molecule of glucose, a 6-carbon compound, is transformed into 2 molecules of pyruvic acid, a 3-carbon compound.
- During the Krebs cycle, pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions.
- The electron transport chain uses the high-energy electrons from glycolysis and the Krebs cycle to convert ADP into ATP.
- Together, glycolysis, the Krebs cycle, and the electron transport chain release about 36 molecules of ATP per molecule of glucose.

#### Key Terms
- glycolysis (254)
- NAD+ (255)
- Krebs cycle (256)
- matrix (256)

### 9.3 Fermentation
- In the absence of oxygen, fermentation releases energy from food molecules by producing ATP.
- For short, quick bursts of energy, the body uses ATP already in muscles as well as ATP made by lactic acid fermentation.
- For exercise longer than about 90 seconds, cellular respiration is the only way to continue generating a supply of ATP.

#### Think Visually
Using the information in this chapter, complete the following compare/contrast table about cellular respiration and fermentation:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cellular Respiration</th>
<th>Fermentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting reactants</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Pathways involved</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>End products</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Number of ATP molecules produced</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

### Comparing Cellular Respiration and Fermentation

#### Performance Tasks
**SUMMATIVE TASK** Have small groups of students write a screenplay that shows how energy is produced in a cell. For example, students might write about a miniature explorer observing the processes of fermentation and cellular respiration, or they might create the screenplay as a first-person account by a carbon atom.

**TRANSFER TASK** Have students keep an exercise journal for a week. Each time they exercise, have them write down the following:
- what type of exercise they performed
- how long they exercised
- how they felt after

Also have them note any changes in appetite on days when they exercised more than usual. Once the journals are complete, have them write a short essay describing how their entries relate to the content of this chapter.

### Answers
**THINK VISUALLY**
1. glucose and oxygen
2. pyruvic acid and NADH
3. glycolysis, Krebs cycle, electron transport chain
4. glycolysis and either lactic acid or alcoholic fermentation
5. carbon dioxide, water, and energy
6. either carbon dioxide, alcohol, and NAD+ or lactic acid and NAD+
7. 36
8. 2

Study Online
**Lesson 9.1**

**UNDERSTAND KEY CONCEPTS**

1. c  2. d  3. b  
4. b  5. d  
6. A calorie is the amount of energy needed to raise the temperature of 1 gram of water 1 degree Celsius. High-calorie molecules are an energy source for cells.  
7. \(6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + \text{Energy, or Oxygen + Glucose} \rightarrow \text{Carbon dioxide + Water + Energy}\)  
8. about 10 percent  
9. A process is anaerobic if it does not directly require oxygen. Glycolysis is anaerobic.

**THINK CRITICALLY**

10. Cellular respiration slowly releases energy through a series of controlled reactions. A fire releases energy more quickly.  
11. Photosynthesis removes carbon dioxide from the atmosphere, and cellular respiration puts it back. Photosynthesis releases oxygen into the atmosphere, and cellular respiration uses that oxygen to release energy from food.

**Lesson 9.2**

**UNDERSTAND KEY CONCEPTS**

12. c  13. c  14. b  
15. During glycolysis, 1 molecule of glucose is transformed into 2 molecules of pyruvic acid.  
16. NAD\(^+\) is an electron carrier. It provides high-energy electrons needed to produce ATP.  
17. Pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions. ATP is produced. In addition, high-energy electrons are carried to the electron transport chain by NADH and FADH\(_2\).  
18. H\(^+\) ions pass across the mitochondrial membrane through ATP synthase, causing the base of the ATP synthase to spin. With each rotation, the enzyme grabs an ADP molecule and attaches a phosphate, producing ATP.  

**THINK CRITICALLY**

19. Both are electron carriers that hold high-energy electrons until they can be transferred to other molecules.  
20. It is found in the inner membrane of the mitochondrial in eukaryotes and in the cell membrane of prokaryotes.  
21. Students’ flowcharts should show that NADH produced in glycolysis and NADH and FADH\(_2\) produced in the Krebs cycle carry high-energy electrons to the electron transport chain, which uses these electrons to produce ATP.  
22. Students should show that glycolysis occurs in the cytoplasm, the Krebs cycle in the mitochondrial matrix, and the electron transport chain in the inner mitochondrial membrane.

**Lesson 9.3**

**UNDERSTAND KEY CONCEPTS**

23. b  24. a  25. b
9.3 Fermentation

**Understand Key Concepts**

23. Because fermentation takes place in the absence of oxygen, it is said to be
   a. aerobic.  b. anaerobic.  c. cyclic.  d. oxygen-rich.

24. The process carried out by yeast that causes bread dough to rise is
   a. alcoholic fermentation.  b. lactic acid fermentation.  c. cellular respiration.  d. yeast mitosis.

25. During heavy exercise, the buildup of lactic acid in muscle cells results in
   a. cellular respiration.  b. fermentation.  c. oxygen debt.  d. the Krebs cycle.

26. How are fermentation and cellular respiration similar?

27. Write equations to show how lactic acid fermentation compares with alcoholic fermentation. Which reactant(s) do they have in common?

**Think Critically**

28. Infer Certain types of bacteria thrive in conditions that lack oxygen. What does that fact indicate about the way they obtain energy?

29. Infer To function properly, heart muscle cells require a steady supply of oxygen. After a heart attack, small amounts of lactic acid are present. What does this evidence suggest about the nature of a heart attack?

30. Predict In certain cases, regular exercise causes an increase in the number of mitochondria in muscle cells. How might that situation improve an individual’s ability to perform energy-requiring activities?

31. Formulate Hypotheses Yeast cells can carry out both fermentation and cellular respiration, depending on whether oxygen is present. In which case would you expect yeast cells to grow more rapidly? Explain.

32. Apply Concepts Carbon monoxide (CO) molecules bring the electron transport chain in a mitochondrion to a stop by binding to an electron carrier. Use this information to explain why carbon monoxide gas kills organisms.

**30. Predict**

Cellular Respiration and Fermentation

30. Predict

To be able to sustain regular 45-minute intervals underwater, whales employ a number of special mechanisms. For example, whale blood is very tolerant of CO₂ buildup that results from the Krebs cycle. This allows whales to stay underwater for an extended period without triggering the reflex to surface. The Krebs cycle and electron transport rely on oxygen, of course. And once the oxygen is used—and it’s used quickly!—whale muscles must rely on lactic acid fermentation to generate energy. In humans, lactic acid causes the pH of the blood to drop. If the blood gets too acidic, a dangerous condition called acidosis can occur. Whale muscles are extremely tolerant of lactic acid. The lactic acid remains in the muscles without causing acidosis. When whales resurface after a long dive, they inhale oxygen that clears away the lactic acid buildup.

**1. Relate Cause and Effect**

Why must whales have blood that is tolerant of CO₂?

**2. Predict**

Myoglobin, a molecule very similar to hemoglobin, stores oxygen in muscles. Would you expect to find more or less myoglobin than average in the muscle tissue of whales if you were to examine it under the microscope?

**3. Infer**

How might being able to dive into very deep water be an advantage for whales such as the sperm whale?

**4. Connect to the Big Idea**

When swimming near the surface, whales breathe every time their heads break out of the water. How do you think the energy pathways used during this type of swimming differ from the ones used during long dives?

**THINK CRITICALLY**

28. These organisms likely obtain energy through the anaerobic process of fermentation.

29. During a heart attack, lactic acid fermentation must occur. Thus, a heart attack must somehow prevent oxygen from reaching cardiac cells which would in turn prevent the heart from functioning properly.

30. More mitochondria would mean more places for cellular respiration to occur, which would result in more production of ATP to be used in energy-requiring activities.

31. Yeast cells would grow more rapidly when oxygen is present because the aerobic process of cellular respiration produces more ATP than the anaerobic process of fermentation.

32. If CO binds to a cell’s electron carriers, no high-energy electrons could be passed down the electron transport chain. The result is reduced production of ATP, the energy source for cells—cells and organisms cannot live without energy.

After students have read through the Chapter Mystery, discuss the topics of energy production and oxygen consumption.

**Ask**

How does your body respond when it is low on oxygen? (I breathe harder and my cells make energy without oxygen.)

**Ask**

Why does it make sense that whales have different adaptations that help them respond to low-oxygen conditions? (Whales live in the ocean. They would have to surface each time they needed to “breathe harder” when they are low on oxygen. That would limit how active they can be underwater and how long they can stay underwater.)

**Ask**

Are whales the only ocean organisms that use oxygen to make energy? (No)

**Ask**

Do you think all ocean organisms have the same adaptations for obtaining oxygen and producing energy as whales? Explain. (Accept all reasonable responses. Sample answer: No, other organisms, like tuna, use gills to obtain oxygen directly from the water rather than the air.)

**CHAPTER MYSTERY ANSWERS**

1. Carbon dioxide is one of the products of the Krebs cycle. In humans, a buildup of CO₂ triggers breathing (this is what makes you gasp if you hold your breath). If this happened in whales, they would need to surface or they would drown.

2. Students should predict that muscle tissue in whales would have more than the average amount of myoglobin, because whales need as much stored oxygen as possible in order to carry out cellular respiration during the long periods they are underwater. (In fact, 41 percent of the oxygen stored in the body during a dive is in the muscles of whales as compared to just 13 percent for humans.)

3. Answers may vary. Being able to dive into deep water is beneficial to whales, because they are able to hunt for food in a larger area of the ocean.

4. When swimming near the surface, the cells of whales can carry out cellular respiration, because the supply of oxygen is available for that process. During long dives, however, when oxygen is not available, cells must carry out lactic acid fermentation to produce ATP for energy.

**For more on marine mammals and cellular respiration suggest students watch Untamed Science: Take a Deep Breath.**
Connecting Concepts

USE SCIENCE GRAPHICS
33. On average, there are 9 Calories in 1 gram of a lipid, 4 Calories in 1 gram of a carbohydrate, and 4 Calories in 1 gram of a protein. The differences are a result of differences in their chemical structures.

34. 4.5 grams of protein
35. 1240 Calories; 62 percent

WRITE ABOUT SCIENCE
36. Answers may vary. For each of the three stages of cellular respiration, the reactants used in the chemical reactions of the stage should be analogized as “deposits” and the products should be analogized as “returns.” The net return for the whole process of cellular respiration is 36 ATP molecules per deposit of 1 glucose molecule.

37. Sketches may vary, though they should accurately show the processes involved in breathing and cellular respiration. The two processes are related in that breathing brings into the body the oxygen needed to carry out cellular respiration and expels from the body carbon dioxide, a product of cellular respiration.

38. Interpret Graphs Based on the graph, at what level of exercise difficulty did oxygen uptake reach 3 L/min?
   a. approximately 100 watts
   b. approximately 200 watts
   c. between 200 and 300 watts
   d. between 300 and 400 watts

39. Formulate Hypotheses Which of the following is a valid hypothesis that explains the trend shown on the graph?
   a. As exercise becomes more difficult, the body relies more and more on lactic acid fermentation.
   b. Exercise below a level of 100 watts does not require increased oxygen uptake.
   c. Difficult exercise requires additional oxygen intake in order to generate extra ATP for muscle cells.
   d. The human body cannot maintain exercise levels above 500 watts.
Standardized Test Prep

Multiple Choice

1. What raw materials are needed for cellular respiration?
   A glucose and carbon dioxide  
   B glucose and oxygen  
   C carbon dioxide and oxygen  
   D oxygen and lactic acid

2. During the Krebs cycle
   A hydrogen ions and oxygen form water.  
   B the cell releases a small amount of energy through fermentation.  
   C each glucose molecule is broken down into 2 molecules of pyruvic acid.  
   D pyruvic acid is broken down into carbon dioxide in a series of reactions.

3. Which substance is needed to begin the process of glycolysis?
   A ATP  
   B NADP  
   C pyruvic acid  
   D carbon dioxide

4. In eukaryotic cells, MOST of cellular respiration takes place in the
   A nuclei.  
   B cytoplasm.  
   C mitochondria.  
   D cell walls.

5. Which substance is broken down during the process of glycolysis?
   A carbon  
   B NAD+  
   C glucose  
   D pyruvic acid

6. The human body can use all of the following as energy sources EXCEPT
   A ATP in muscles.  
   B glycolysis.  
   C lactic acid fermentation.  
   D alcoholic fermentation.

7. During cellular respiration, which of the following are released as byproducts?
   A CO₂ and O₂  
   B H₂O and O₂  
   C O₂ and H₂O  
   D CO₂ and H₂O

8. Which of the following is an aerobic process?
   A the Krebs cycle  
   B glycolysis  
   C alcoholic fermentation  
   D lactic acid fermentation

Questions 9 and 10

The graph below shows the rate of alcoholic fermentation for yeast at different temperatures.

![Rate of Fermentation Versus Temperature Graph]

9. According to the graph, what is the relationship between the rate of fermentation and temperature?
   A The rate of fermentation continually increases as temperature increases.  
   B The rate of fermentation continually decreases as temperature increases.  
   C The rate of fermentation increases with temperature at first, and then it rapidly decreases.  
   D The rate of fermentation decreases with temperature at first, and then it rapidly increases.

10. Which statement could explain the data shown in the graph?
    A The molecules that regulate fermentation perform optimally at temperatures above 30°C.  
    B The yeast begins releasing carbon dioxide at 30°C.  
    C The yeast cannot survive above 30°C.  
    D The molecules that regulate fermentation perform optimally at temperatures below 10°C.

Open-Ended Response

11. Explain how a sprinter gets energy during a 30-second race. Is the process aerobic or anaerobic? How does it compare to a long-distance runner getting energy during a 5-kilometer race?

If You Have Trouble With . . .

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
</table>

Test-Taking Tip

INTERPRET GRAPHS

When answering questions about a line graph, suggest students first take the time to analyze the graph before reading the questions. Begin by looking at the shape of the line. Then, identify the variables labeled on each of the graph’s axes. Try to determine how the variables are related. That is, determine how one variable changes in response to changes in the other variable. Finally, look again at the line. After analyzing the graph, read and answer the questions that relate to the graph.
Chapter 10
Cell Growth and Division

Growth, Development, and Reproduction

Q: How does a cell produce a new cell?
Julia stared into the salamander tank in horror. As an assistant in a pet shop, Julia had mistakenly put a small salamander in the same tank as a large one. Just as she realized her error, the large salamander attacked and bit off one of the small salamander’s limbs.

Acting quickly, Julia scooped up the injured salamander and put it in its own tank. She was sure it would die before her shift ended. But she was wrong! Days passed… then weeks. Every time Julia checked on the salamander, she was more amazed at what she saw. How did the salamander’s body react to losing a limb? As you read this chapter, look for clues to help you predict the salamander’s fate. Think about the cell processes that would be involved. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the Pet Shop mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.
10.1 Cell Growth, Division, and Reproduction

Key Questions

- What are some of the difficulties a cell faces as it increases in size?
- How do asexual and sexual reproduction compare?

Vocabulary

cell division
asexual reproduction
sexual reproduction

Taking Notes

Outline As you read, create an outline about cell growth, division, and reproduction. As you read, fill in key phrases or sentences about each heading.

THINK ABOUT IT When a living thing grows, what happens to its cells? Does an organism get larger because each cell increases in size or because it produces more of them? In most cases, living things grow by producing more cells. What is there about growth that requires cells to divide and produce more of themselves?

Limits to Cell Size

- What are some of the difficulties a cell faces as it increases in size?

Nearly all cells can grow by increasing in size, but eventually, most cells divide after growing to a certain point. There are two main reasons why cells divide rather than continuing to grow. The larger a cell becomes, the more demands the cell places on its DNA. In addition, a larger cell is less efficient in moving nutrients and waste materials across the cell membrane.

Information “Overload” Living cells store critical information in a molecule known as DNA. As a cell grows, that information is used to build the molecules needed for cell growth. But as a cell increases in size, its DNA does not. If a cell were to grow too large, an “information crisis” would occur.

To get a better sense of information overload, compare a cell to a growing town. Suppose a small town has a library with a few thousand books. As more people move in, more people will borrow books. Sometimes, people may have to wait to borrow popular books. Similarly, a larger cell would make greater demands on its genetic “library.” After a while, the DNA would no longer be able to serve the needs of the growing cell—it might be time to build a new library.

Exchanging Materials There is another critical reason why cell size is limited. Food, oxygen, and water enter a cell through its cell membrane. Waste products leave a cell in the same way. The rate at which this exchange takes place depends on the surface area of the cell, which is the total area of its cell membrane. The rate at which food and oxygen are used up and waste products are produced depends on the cell’s volume. Understanding the relationship between a cell’s surface area and its volume is the key to understanding why cells must divide rather than continue to grow.
#### Ratio of Surface Area to Volume

Imagine a cell that is shaped like a cube, like those shown in Figure 10–1. The formula for area ($l \times w$) is used to calculate the surface area. The formula for volume ($l \times w \times h$) is used to calculate the amount of space inside. By using a ratio of surface area to volume, you can see how the size of the cell’s surface area grows compared to its volume.

Notice that for a cell with sides that measure 1 cm in length, the ratio of surface area to volume is $6/1$ or $6:1$. Increase the length of the cell’s sides to 2 cm, and the ratio becomes $24/8$ or $3:1$. What if the length triples? The ratio of surface area to volume becomes $54/27$ or $2:1$. Notice that the surface area is not increasing as fast as the volume increases. For a growing cell, a decrease in the relative amount of cell membrane available creates serious problems.

<table>
<thead>
<tr>
<th>Surface Area (length $\times$ width) $\times$ 6 sides</th>
<th>Volume (length $\times$ width $\times$ height)</th>
<th>Ratio of Surface Area to Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \text{ cm} \times 1 \text{ cm} \times 6 = 6 \text{ cm}^2$</td>
<td>$1 \text{ cm} \times 1 \text{ cm} \times 1 \text{ cm} = 1 \text{ cm}^3$</td>
<td>$6 / 1 = 6:1$</td>
</tr>
<tr>
<td>$2 \text{ cm} \times 2 \text{ cm} \times 6 = 24 \text{ cm}^2$</td>
<td>$2 \text{ cm} \times 2 \text{ cm} \times 2 \text{ cm} = 8 \text{ cm}^3$</td>
<td>$24 / 8 = 3:1$</td>
</tr>
<tr>
<td>$3 \text{ cm} \times 3 \text{ cm} \times 6 = 54 \text{ cm}^2$</td>
<td>$3 \text{ cm} \times 3 \text{ cm} \times 3 \text{ cm} = 27 \text{ cm}^3$</td>
<td>$54 / 27 = 2:1$</td>
</tr>
</tbody>
</table>

#### Quick Lab: Open-Ended Inquiry

**Modeling the Relationship Between Surface Area and Volume**

1. Use the drawing and grid paper to make patterns for a 6-cm cube, a 5-cm cube, a 4-cm cube, and a 3-cm cube.
2. Cut out your patterns and fold them. Then use the tabs to tape or glue the sides together. Don’t tape down the top side.
3. Construct a data table to compare the volume, the surface area, and the ratio of surface area to volume of each cube.
4. Use your data to calculate the number of 3-cm cubes that would fit in the same volume as the 6-cm cube. Also calculate the total surface area for the smaller cubes.

**Analyze and Conclude**

1. **Review** Describe the function of a cell membrane and its relationship to what happens inside a cell.
2. **Apply Concepts** How does the surface area change when a large cell divides into smaller cells that have the same total volume?
GROWING PAINS

FIGURE 10–2 Lots of growth can mean lots of trouble—both in a town and in a cell. Use Analogies How could cell growth create a problem that is similar to a traffic jam?

Traffic Problems To use the town analogy again, suppose the town has just a two-lane main street leading to the center of town. As the town grows, more and more traffic clogs the main street. It becomes increasingly difficult to move goods in and out.

A cell that continues to grow would experience similar problems. If a cell got too large, it would be more difficult to get sufficient amounts of oxygen and nutrients in and waste products out. This is another reason why cells do not continue to grow larger even if the organism does.

Division of the Cell Before it becomes too large, a growing cell divides, forming two “daughter” cells. The process by which a cell divides into two new daughter cells is called cell division.

Before cell division occurs, the cell replicates, or copies all of its DNA. This replication of DNA solves the problem of information overload because each daughter cell gets one complete copy of genetic information. Cell division also solves the problem of increasing size by reducing cell volume. Cell division results in an increase in the ratio of surface area to volume for each daughter cell. This allows for the efficient exchange of materials within a cell.
Replication, the formation of new individuals, is one of the most important characteristics of living things. For an organism composed of just one cell, cell division can serve as a perfectly good form of reproduction. You don’t have to meet someone else, conduct a courtship, or deal with rivals. All you have to do is to divide, and presto—there are two of you!

**Asexual Reproduction** For many single-celled organisms, such as the bacterium in Figure 10–3, cell division is the only form of reproduction. The process can be relatively simple, efficient, and effective, enabling populations to increase in number very quickly. In most cases, the two cells produced by cell division are genetically identical to the cell that produced them. This kind of reproduction is called asexual reproduction. The production of genetically identical offspring from a single parent is known as asexual reproduction.

Asexual reproduction also occurs in many multicellular organisms. The small bud growing off the hydra will eventually break off and become an independent organism, an example of asexual reproduction in an animal. Each of the small shoots or plantlets on the tip of the kalanchoe leaf may also grow into a new plant.

**Sexual Reproduction** Unlike asexual reproduction, where cells separate to form a new individual, sexual reproduction involves the fusion of two separate parent cells. In sexual reproduction, offspring are produced by the fusion of special reproductive cells formed by each of two parents. Offspring produced by sexual reproduction inherit some of their genetic information from each parent. Most animals and plants reproduce sexually, and so do some single-celled organisms. You will learn more about the form of cell division that produces reproductive cells in Chapter 11.

**Apply Concepts** What do the offspring of each of these organisms have in common?

**In Your Notebook** Use a Venn diagram to compare asexual and sexual reproduction.

**BUILD Vocabulary**

**PREFIXES** The prefix *a-* in *asexual* means “without.” Asexual reproduction is reproduction without the fusion of reproductive cells.
Comparing Asexual and Sexual Reproduction  You can see that each type of reproduction has its advantages and disadvantages when you look at each one as a strategy for survival. Species survive by reproducing. The better suited a species is to its environment, the greater its chance of survival.

For single-celled organisms, asexual reproduction is a survival strategy. When conditions are right, the faster they reproduce, the better their chance of survival over other organisms using the same resources. Having offspring that are genetically identical is also an advantage as long as conditions remain favorable. However, a lack of genetic diversity becomes a disadvantage when conditions change in ways that do not fit the characteristics of an organism.

Sexual reproduction is a different type of survival strategy. The process of finding a mate and the growth and development of offspring require more time. However, this can be an advantage for species that live in environments where seasonal changes affect weather conditions and food availability. Sexual reproduction also provides genetic diversity. If an environment changes, some offspring may have the right combination of characteristics needed to survive.

Some organisms reproduce both sexually and asexually. Yeasts, for example, are single-celled eukaryotes that use both strategies. They reproduce asexually most of the time. However, under certain conditions, they enter a sexual phase. The different advantages of each type of reproduction may help to explain why the living world includes organisms that reproduce sexually, those that reproduce asexually, and many organisms that do both.
THINK ABOUT IT What role does cell division play in your life? You know from your own experience that living things grow, or increase in size, during particular stages of life or even throughout their lifetime. This growth clearly depends on the production of new cells through cell division. But what happens when you are finished growing? Does cell division simply stop? Think about what must happen when your body heals a cut or a broken bone. And finally, think about the everyday wear and tear on the cells of your skin, digestive system, and blood. Cell division has a role to play there, too.

Chromosomes

What is the role of chromosomes in cell division?

What do you think would happen if a cell were simply to split in two, without any advance preparation? The results might be disastrous, especially if some of the cell’s essential genetic information wound up in one of the daughter cells, and not in the other. In order to make sure this doesn’t happen, cells first make a complete copy of their genetic information before cell division begins.

Even a small cell like the bacterium E. coli has a tremendous amount of genetic information in the form of DNA. In fact, the total length of this bacterium’s DNA molecule is 1.6 mm, roughly 1000 times longer than the cell itself. In terms of scale, imagine a 300-meter rope stuffed into a school backpack. Cells can handle such large molecules only by careful packaging. Genetic information is bundled into packages of DNA known as chromosomes.

Prokaryotic Chromosomes Prokaryotes lack nuclei and many of the organelles found in eukaryotes. Their DNA molecules are found in the cytoplasm along with most of the other contents of the cell. Most prokaryotes contain a single, circular DNA chromosome that contains all, or nearly all, of the cell’s genetic information.

FIGURE 10–4 Prokaryotic Chromosome In most prokaryotes, a single chromosome holds most of the organism’s DNA.
Eukaryotic Chromosomes  Eukaryotic cells generally have much more DNA than prokaryotes have and, therefore, contain multiple chromosomes. Fruit flies, for example, have 8 chromosomes per cell, human cells have 46, and carrot cells have 18. The chromosomes in eukaryotic cells form a close association with histones, a type of protein. This complex of chromosome and protein is referred to as chromatin. DNA tightly coils around the histones, and together, the DNA and histone molecules form beadlike structures called nucleosomes. Nucleosomes pack together to form thick fibers, which condense even further during cell division. Usually the chromosome shape you see drawn is a duplicated chromosome with supercoiled chromatin, as shown in Figure 10–5.

Why do cells go to such lengths to package their DNA into chromosomes? One of the principal reasons is to ensure equal division of DNA when a cell divides. Chromosomes make it possible to separate DNA precisely during cell division.

In Your Notebook  Write instructions to build a eukaryotic chromosome.

The Cell Cycle

What are the main events of the cell cycle?

Cells go through a series of events known as the cell cycle as they grow and divide. During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells. Each daughter cell then moves into a new cell cycle of activity, growth, and division.
The Prokaryotic Cell Cycle  The prokaryotic cell cycle is a regular pattern of growth, DNA replication, and cell division that can take place very rapidly under ideal conditions. Researchers are only just beginning to understand how the cycle works in prokaryotes, and relatively little is known about its details. It is known that most prokaryotic cells begin to replicate, or copy, their DNA chromosomes once they have grown to a certain size. When DNA replication is complete, or nearly complete, the cell begins to divide.

The process of cell division in prokaryotes is a form of asexual reproduction known as binary fission. Once the chromosome has been replicated, the two DNA molecules attach to different regions of the cell membrane. A network of fibers forms between them, stretching from one side of the cell to the other. The fibers constrict and the cell is pinched inward, dividing the cytoplasm and chromosomes between two newly formed cells. Binary fission results in the production of two genetically identical cells.

The Eukaryotic Cell Cycle In contrast to prokaryotes, much more is known about the eukaryotic cell cycle. As you can see in Figure 10–7, the eukaryotic cell cycle consists of four phases: G\(_1\), S, G\(_2\), and M. The length of each part of the cell cycle—and the length of the entire cell cycle—varies depending on the type of cell.

At one time, biologists described the life of a cell as one cell division after another separated by an “in-between” period of growth called interphase. We now appreciate that a great deal happens in the time between cell divisions. Interphase is divided into three parts: G\(_1\), S, and G\(_2\).

\textbf{G\(_1\) Phase: Cell Growth} Cells do most of their growing during the G\(_1\) phase. In this phase, cells increase in size and synthesize new proteins and organelles. The G in G\(_1\) and G\(_2\) stands for “gap,” but the G\(_1\) and G\(_2\) phases are actually periods of intense growth and activity.

\textbf{S Phase: DNA Replication} The G\(_1\) phase is followed by the S phase. The S stands for “synthesis.” During the S phase, new DNA is synthesized when the chromosomes are replicated. The cell at the end of the S phase contains twice as much DNA as it did at the beginning.

\textbf{FIGURE 10–7 The Cell Cycle} During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells. The cell cycle includes four phases—G\(_1\), S, G\(_2\), and M. Infer During which phase or phases would you expect the amount of DNA in the cell to change?
**G₂ Phase: Preparing for Cell Division** When DNA replication is completed, the cell enters the G₂ phase. G₂ is usually the shortest of the three phases of interphase. During the G₂ phase, many of the organelles and molecules required for cell division are produced. When the events of the G₂ phase are completed, the cell is ready to enter the M phase and begin the process of cell division.

**M Phase: Cell Division** The M phase of the cell cycle, which follows interphase, produces two daughter cells. The M phase takes its name from the process of mitosis. During the normal cell cycle, in interphase, produces two daughter cells. The M phase takes its name completed, the cell enters the G₁ phase. If no events of the G₂ phase are completed, the cell is ready to enter the G₁ phase. G₂ phase is usually the shortest of the three phases of interphase. During the G₂ phase, many of the organelles and molecules required for cell division are produced. When the events of the G₂ phase are completed, the cell is ready to enter the M phase and begin the process of cell division.

In eukaryotes, cell division occurs in two main stages. The first stage of the process, division of the cell nucleus, is called **mitosis** (my TÖH sis). The second stage, the division of the cytoplasm, is called **cytokinesis** (sy toh kih nee sis). In many cells, the two stages may overlap, so that cytokinesis begins while mitosis is still taking place.

**Mitosis**

**What events occur during each of the four phases of mitosis?**

Biologists divide the events of mitosis into four phases: prophase, metaphase, anaphase, and telophase. Depending on the type of cell, mitosis may last anywhere from a few minutes to several days. Figure 10–8 through Figure 10–11 show mitosis in an animal cell.

**Prophase** The first phase of mitosis, **prophase**, is usually the longest and may take up to half of the total time required to complete mitosis. During prophase, the genetic material inside the nucleus condenses and the duplicated chromosomes become visible. Outside the nucleus, a spindle starts to form.

The duplicated strands of the DNA molecule can be seen to be attached along their length at an area called the **centromere**. Each DNA strand in the duplicated chromosome is referred to as a **chromatid** (kroh muh tid), or sister chromatid. When the process of mitosis is complete, the chromatids will have separated and been divided between the new daughter cells.

Also during prophase, the cell starts to build a spindle, a fanlike system of microtubules that will help to separate the duplicated chromosomes. Spindle fibers extend from a region called the centrosome, where tiny paired structures called **centrioles** are located. Plant cells lack centrioles, and organize spindles directly from their centrosome regions. The centrioles, which were duplicated during interphase, start to move toward opposite ends, or poles, of the cell. As prophase ends, the chromosomes coil more tightly, the nucleolus disappears, and the nuclear envelope breaks down.

**Metaphase** The second phase of mitosis, **metaphase**, is generally the shortest. During metaphase, the centromeres of the duplicated chromosomes line up across the center of the cell. Spindle fibers connect the centromere of each chromosome to the two poles of the spindle.

**FIGURE 10–8 Prophase**

Spindle forming

Centrioles

Nuclear envelope

Centromere

Chromosomes

**FIGURE 10–9 Metaphase**

Spindle

Metaphase

The genetic material inside the nucleus condenses and the duplicated chromosomes become visible. Outside the nucleus, a spindle starts to form.

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Mitosis in Action

1. Examine a slide of a stained onion root tip under a microscope. Viewing the slide under low power, adjust the stage until you find the boxlike cells just above the root tip.

2. Switch the microscope to high power and locate cells that are in the process of dividing.

3. Find and sketch cells that are in each phase of mitosis. Label each sketch with the name of the appropriate phase.

Analyze and Conclude

1. **Observe** In which phase of the cell cycle were most of the cells you observed? Why do you think this is?

2. **Draw Conclusions** What evidence did you observe that shows mitosis is a continuous process, not a series of separate events?

3. **Apply Concepts** Cells in the root divide many times as the root grows longer and thicker. With each cell division, the chromosomes are divided between two daughter cells, yet the number of chromosomes in each cell does not change. What processes ensure that the normal number of chromosomes is restored after each cell division?
Cytokinesis

How do daughter cells split apart after mitosis?

As a result of mitosis, two nuclei—each with a duplicate set of chromosomes—are formed. All that remains to complete the M phase of the cycle is cytokinesis, the division of the cytoplasm itself. Cytokinesis usually occurs at the same time as telophase. Cytokinesis completes the process of cell division—it splits one cell into two. The process of cytokinesis differs in animal and plant cells.

Cytokinesis in Animal Cells During cytokinesis in most animal cells, the cell membrane is drawn inward until the cytoplasm is pinched into two nearly equal parts. Each part contains its own nucleus and cytoplasmic organelles.

Cytokinesis in Plant Cells Cytokinesis in plant cells proceeds differently. The cell membrane is not flexible enough to draw inward because of the rigid cell wall that surrounds it. Instead, a structure known as the cell plate forms halfway between the divided nuclei. The cell plate gradually develops into cell membranes that separate the two daughter cells. A cell wall then forms in between the two new membranes, completing the process.

**FIGURE 10–12 Cytokinesis**
The division of the cytoplasm occurs differently in animal and plant cells.

**Draw Conclusions** What else, other than cytoplasm, is divided between the two new cells during cytokinesis?

**Summary**
5. Summarize what happens during interphase. Be sure to include all three parts of interphase. *Hint: Include all of the main details in your summary.*
MITOSIS

**FIGURE 10–13** The phases of mitosis shown here are typical of eukaryotic cells. These light micrographs are from a developing whitefish embryo (LM 415X).

**Infer** Why is the timing between what happens to the nuclear envelope and the activity of the mitotic spindle so critical?

**Interphase**
The cell grows and replicates its DNA and centrioles.

**Cytokinesis**
The cytoplasm pinches in half. Each daughter cell has an identical set of duplicate chromosomes.

**Prophase**
The chromatin condenses into chromosomes. The centrioles separate, and a spindle begins to form. The nuclear envelope breaks down.

**Telophase**
The chromosomes gather at opposite ends of the cell and lose their distinct shapes. Two new nuclear envelopes will form.

**Metaphase**
The chromosomes line up across the center of the cell. Each chromosome is connected to spindle fibers at its centromere.

**Anaphase**
The sister chromatids separate into individual chromosomes and are moved apart.
Regulating the Cell Cycle

Key Questions

- How is the cell cycle regulated?
- How do cancer cells differ from other cells?

Vocabulary

cyclin
growth factor
apoptosis
cancer
tumor

Taking Notes

Concept Map As you read, create a concept map to organize the information in this lesson.

THINK ABOUT IT How do cells know when to divide? One striking fact about cells in multicellular organisms is how carefully cell growth and cell division are controlled. Not all cells move through the cell cycle at the same rate.

In the human body, for example, most muscle cells and nerve cells do not divide at all once they have developed. In contrast, cells in the bone marrow that make blood cells and cells of the skin and digestive tract grow and divide rapidly throughout life. These cells may pass through a complete cycle every few hours. This process provides new cells to replace those that wear out or break down.

Controls on Cell Division

How is the cell cycle regulated?

When scientists grow cells in the laboratory, most cells will divide until they come into contact with each other. Once they do, they usually stop dividing and growing. What happens if those neighboring cells are suddenly scraped away in the culture dish? The remaining cells will begin dividing again until they once again make contact with other cells. This simple experiment shows that controls on cell growth and division can be turned on and off.

Something similar happens inside the body. Look at Figure 10–14. When an injury such as a cut in the skin or a break in a bone occurs, cells at the edges of the injury are stimulated to divide rapidly. New cells form, starting the process of healing. When the healing process nears completion, the rate of cell division slows, controls on growth are restored, and everything returns to normal.

The Discovery of Cyclins For many years, biologists searched for a signal that might regulate the cell cycle—something that would “tell” cells when it was time to divide, duplicate their chromosomes, or enter another phase of the cell cycle.

In the early 1980s, biologists discovered a protein in cells that were in mitosis. When they injected the protein into a nondividing cell, a mitotic spindle would form. They named this protein cyclin because it seemed to regulate the cell cycle. Investigators have since discovered a family of proteins known as cyclins that regulate the timing of the cell cycle in eukaryotic cells.

BUILD Vocabulary

ACADEMIC WORDS The verb regulate means “to control or direct.” Therefore, a substance that regulates the cell cycle controls when the cell grows and divides.
Regulatory Proteins  The discovery of cyclins was just the start. Scientists have since identified dozens of other proteins that also help to regulate the cell cycle. The cell cycle is controlled by regulatory proteins both inside and outside the cell.

▶ Internal Regulators  One group of proteins, internal regulatory proteins, respond to events occurring inside a cell. Internal regulatory proteins allow the cell cycle to proceed only when certain events have occurred in the cell itself. For example, several regulatory proteins make sure a cell does not enter mitosis until its chromosomes have replicated. Another regulatory protein prevents a cell from entering anaphase until the spindle fibers have attached to the chromosomes.

▶ External Regulators  Proteins that respond to events outside the cell are called external regulatory proteins. External regulatory proteins direct cells to speed up or slow down the cell cycle.

One important group of external regulatory proteins is the group made up of the growth factors. Growth factors stimulate the growth and division of cells. These proteins are especially important during embryonic development and wound healing. Other external regulatory proteins on the surface of neighboring cells often have an opposite effect. They cause cells to slow down or stop their cell cycles. This prevents excessive cell growth and keeps body tissues from disrupting one another.

In Your Notebook  Use a cause-and-effect diagram to describe how internal and external regulators work together to control the cell cycle.
The Rise and Fall of Cyclins

Scientists measured cyclin levels in clam egg cells as the cells went through their first mitotic divisions after fertilization. The data are shown in the graph.

Cyclins are continually produced and destroyed within cells. Cyclin production signals cells to enter mitosis, while cyclin destruction signals cells to stop dividing and enter interphase.

1. **Interpret Graphs** How long does cyclin production last during a typical cell cycle in fertilized clam eggs?

2. **Infer** During which part of the cell cycle does cyclin production begin? How quickly is cyclin destroyed?

3. **Predict** Suppose that the regulators that control cyclin production are no longer produced. What are two possible outcomes?

---

**Apoptosis** Just as new cells are produced every day in a multicellular organism, many other cells die. Cells end their life cycle in one of two ways. A cell may die by accident due to damage or injury, or a cell may actually be “programmed” to die. **Apoptosis** (ayp up TOH sis) is a process of programmed cell death. Once apoptosis is triggered, a cell undergoes a series of controlled steps leading to its self-destruction. First, the cell and its chromatin shrink, and then parts of the cell’s membranes break off. Neighboring cells then quickly clean up the cell’s remains.

Apoptosis plays a key role in development by shaping the structure of tissues and organs in plants and animals. For example, look at the photos of a mouse foot in **Figure 10–15**. Each foot of a mouse is shaped the way it is partly because cells between the toes die by apoptosis during tissue development. When apoptosis does not occur as it should, a number of diseases can result. For example, the cell loss seen in AIDS and Parkinson’s disease can result if too much apoptosis occurs.

**FIGURE 10–15 Apoptosis** The cells between a mouse’s toes undergo apoptosis during a late stage of development. **Predict** What is one way the pattern of apoptosis would differ in foot development for a duck?
Cancer: Uncontrolled Cell Growth

How do cancer cells differ from other cells? Why is cell growth regulated so carefully? The principal reason may be that the consequences of uncontrolled cell growth in a multicellular organism are very severe. Cancer, a disorder in which body cells lose the ability to control growth, is one such example.

Cancer cells do not respond to the signals that regulate the growth of most cells. As a result, the cells divide uncontrollably. Cancer cells form a mass of cells called a tumor. However, not all tumors are cancerous. Some tumors are benign, or noncancerous. A benign tumor does not spread to surrounding healthy tissue or to other parts of the body. Cancerous tumors, such as the one in Figure 10–16, are malignant. Malignant tumors invade and destroy surrounding healthy tissue.

As the cancer cells spread, they absorb the nutrients needed by other cells, block nerve connections, and prevent the organs they invade from functioning properly. Soon, the delicate balances that exist in the body are disrupted, and life-threatening illness results.

What Causes Cancer? Cancers are caused by defects in the genes that regulate cell growth and division. There are several sources of such defects, including: smoking or chewing tobacco, radiation exposure, other defective genes, and even viral infection. All cancers, however, have one thing in common: The control over the cell cycle has broken down. Some cancer cells will no longer respond to external growth regulators, while others fail to produce the internal regulators that ensure orderly growth.

An astonishing number of cancer cells have a defect in a gene called p53, which normally halts the cell cycle until all chromosomes have been properly replicated. Damaged or defective p53 genes cause cells to lose the information needed to respond to signals that normally control their growth.

In Your Notebook Use a two-column chart to compare the controls that regulate normal cell growth to the lack of control seen in cancer cells.

FIGURE 10–16 Growth of Cancer Cells Normal cells grow and divide in a carefully controlled fashion. Cells that are cancerous lose this control and continue to grow and divide, producing tumors.

1 A cell begins to divide abnormally.

2 The cancer cells produce a tumor, which begins to displace normal cells and tissues.

3 Cancer cells are particularly dangerous because of their tendency to spread once they enter the bloodstream or lymph vessels. The cancer then moves into other parts of the body and forms secondary tumors, a process called metastasis.
Treatments for Cancer  When a cancerous tumor is localized, it can often be removed by surgery. Skin cancer, the most common form of the disease, can usually be treated this way. Melanomas, the most serious form of skin cancer, can be removed surgically, but only if spotted very early.

Other forms of treatment make use of the fact that cancer cells grow rapidly and, therefore, need to copy their DNA more quickly than do most normal cells. This makes them especially vulnerable to damage from radiation. As a result, many tumors can be effectively treated with carefully targeted beams of radiation.

Medical researchers have worked for years to develop chemical compounds that would kill cancer cells, or at least slow their growth. The use of such compounds against cancer is known as chemotherapy. Great advances in chemotherapy have taken place in recent years and have even made it possible to cure some forms of cancer. However, because most chemotherapy compounds target rapidly dividing cells, they also interfere with cell division in normal, healthy cells. This produces serious side effects in many patients, and it is one of the reasons why scientists are so interested in gaining a better understanding of the role of cell cycle proteins in cancer. The goal of many researchers is to find highly specific ways in which cancer cells can be targeted for destruction while leaving healthy cells unaffected.

Cancer is a serious disease. Understanding and combating cancer remains a major scientific challenge, but scientists at least know where to start. Cancer is a disease of the cell cycle, and conquering cancer will require a much deeper understanding of the processes that control cell division.

**Review Key Concepts**

1. **a. Review** Name the two types of proteins that regulate the cell cycle. How do these proteins work?
   **b. Form a Hypothesis** Write a hypothesis about what you think would happen if cyclin were injected into a cell during mitosis. How could you test your hypothesis?

2. **a. Review** Why is cancer considered a disease of the cell cycle?
   **b. Compare and Contrast** How are the growth of a tumor and the repair of a scrape on your knee similar? How are they different?
Suppose you are a cell biologist studying cell division and cancer. What might you use a fluorescence microscope to study? Describe your ideas in a paragraph.
**Key Questions**

- How do cells become specialized for different functions?
- What are stem cells?
- What are some possible benefits and issues associated with stem cell research?

**Vocabulary**
- embryo
- differentiation
- totipotent
- blastocyst
- pluripotent
- stem cell
- multipotent

**From One Cell to Many**

**How do cells become specialized for different functions?**

Each of us started life as just one cell. So, for that matter, did your pet dog, an earthworm, and the petunia on the windowsill. These living things pass through a developmental stage called an **embryo**, from which the adult organism is gradually produced. During the development process, an organism’s cells become more and more differentiated and specialized for particular functions. **Figure 10–18** shows some of the specialized cells found in the roots, stems, and leaves of a plant.

**THINK ABOUT IT**

The human body contains an estimated 100,000,000,000,000 (one hundred trillion) cells. That’s a staggering number, but in one respect it’s not quite as large as you might think. Why? Try to estimate how many times a single cell would have to divide through mitosis to produce that many cells. It may surprise you to learn that as few as 47 rounds of cell division can produce that many cells.

The results of those 47 cell cycles are truly amazing. The human body contains hundreds of distinctly different cell types, and every one of them develops from the single cell that starts the process. How do the cells get to be so different from each other?

**Comparing and Contrasting with a Table**

As you read, create a table comparing the ability of different cell types to differentiate.

**FIGURE 10–18 Specialized Plant Cells**

- Cells that store sugar
- Cells that transport materials
- Cells that carry out photosynthesis
Defining Differentiation  The process by which cells become specialized is known as differentiation (dif ur en shee AY shun). During the development of an organism, cells differentiate into many types of cells. A differentiated cell has become, quite literally, different from the embryonic cell that produced it, and specialized to perform certain tasks, such as contraction, photosynthesis, or protection. Our bodies, and the bodies of all multicellular organisms, contain highly differentiated cells that carry out the jobs we need to perform to stay alive.

Mapping Differentiation  The process of differentiation determines a cell’s ultimate identity, such as whether it will spend its life as a nerve cell or a muscle cell. In some organisms, a cell’s role is rigidly determined at a specific point in the course of development. In the microscopic worm Caenorhabditis elegans, for example, biologists have mapped the outcome of each and every cell division from fertilized egg to adult.

The process of cell differentiation in C. elegans begins with the very first division and continues throughout embryonic development. Figure 10–19 shows when some of the cells found in the adult begin to differentiate during development. Each and every time a new worm develops, the process is the same, resulting in 959 cells with precisely determined functions.

Differentiation in Mammals  Other organisms, including mammals like us, go through a more flexible process in which cell differentiation is controlled by a number of interacting factors in the embryo, many of which are still not well understood. What is known, however, is that adult cells generally do reach a point at which their differentiation is complete—when they can no longer become other types of cells.

In Your Notebook  Starting with a single cell, calculate how many cells might result after 4, 8, and 10 cell divisions.
Cellular Differentiation of *C. elegans*

The adult microscopic worm *C. elegans* contains 959 cells. The data table shows some of the different cell types in this worm. Copy the data table into your notebook and answer the following questions.

1. **Calculate**  
   Calculate the percentage of the total cell number represented by each tissue or organ listed by using this formula:
   \[
   \frac{\text{Number of cells in adult}}{\text{Total number of cells}} \times 100
   \]

2. **Calculate**  
   Find both the number of cells and the percentage of the total represented by cells in tissues or organs not listed (“other”). The category includes cells from, among other organs, the intestine. Record the results in your table.

### Data Table

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Number of Cells in Adult</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuticle</td>
<td>213</td>
<td>22%</td>
</tr>
<tr>
<td>Gonad (excluding germ line cells)</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>Mesoderm muscle</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Pharynx</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. **Infer**  
   Why does *C. elegans* make an ideal model for studying cellular differentiation?

4. **Infer**  
   Why would it be more difficult to map the differentiation patterns in a different organism, such as a mammal?

**Stem Cells and Development**

**What are stem cells?**

One of the most important questions in biology is how all of the specialized, differentiated cell types in the body are formed from just a single cell. Biologists say that such a cell is **totipotent** (toh tih puh tunt), literally able to do everything, to develop into any type of cell in the body (including the cells that make up the extraembryonic membranes and placenta). Only the fertilized egg and the cells produced by the first few cell divisions of embryonic development are truly totipotent. If there is a “secret” by which cells start the process of differentiation, these are the cells that know that secret.

**Human Development**  
After about four days of development, a human embryo forms into a **blastocyst**, a hollow ball of cells with a cluster of cells inside known as the inner cell mass. Even at this early stage, the cells of the blastocyst have begun to specialize. The outer cells form tissues that attach the embryo to its mother, while the inner cell mass becomes the embryo itself. The cells of the inner cell mass are said to be pluripotent (plu rip uh tunt). Cells that are **pluripotent** can develop into most, but not all, of the body’s cell types. They cannot form the tissues surrounding the embryo.

**In Your Notebook**  
Look up the roots that form the words totipotent, pluripotent, and multipotent. How do the roots relate to each cell’s ability to differentiate?
The unspecialized cells from which differentiated cells develop are known as stem cells. As the name implies, stem cells sit at the base of a branching “stem” of development from which different cell types form. Because of their potential to develop into other cell types, stem cells are the subject of intense interest by researchers around the world.

**Embryonic Stem Cells**  As you have seen, the pluripotent stem cells of the inner cell mass eventually produce all of the cells of the body. Embryonic stem cells are pluripotent cells found in the early embryo. In 1998, researchers at the University of Wisconsin found a way to grow these embryonic stem cells in culture. Their experiments confirmed that such cells did indeed have the capacity to produce just about any cell type in the human body. In fact, scientists have managed to coax mouse embryonic stem cells to differentiate into nerve cells, muscle cells, and even into sperm and egg cells. Recently, sperm made from embryonic stem cells were used to generate live mice.

**Adult Stem Cells**  For years, biologists have suspected that adult organisms might also contain some types of stem cells. Cells in the blood and skin, for example, have a limited life span and must be constantly replaced. This suggests that the body contains pools of stem cells from which new skin and blood cells can be produced.

Adult stem cells are groups of cells that differentiate to renew and replace cells in the adult body. Because of their more limited potential, adult stem cells are referred to as multipotent (muh-TIP uh TUN-t), meaning that they can develop into many types of differentiated cells. Typically, stem cells of a given organ or tissue produce only the types of cells that are unique to that tissue. For example, adult stem cells in the bone marrow can develop into several different types of blood cells, while stem cells in the brain can produce neurons, or nerve cells.
Stem cells are filtered from bone marrow removed from a patient’s hip. The stem cells are injected into the heart’s damaged area. The environment of the heart stimulates injected stem cells to differentiate into new heart muscle cells.

**FIGURE 10–21 A Possible Future Treatment for Heart Disease?** Stem cell research may lead to new ways to reverse the damage caused by a severe heart attack. The diagram shows one method currently being investigated. **Infer** How would the fate of the stem cells change after they are moved from the bone marrow to the heart?

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**Frontiers in Stem Cell Research**

What are some possible benefits and issues associated with stem cell research?

Understanding how stem cells retain the capacity to differentiate into so many cell types is an important unsolved problem in biology. Scientists would like to learn exactly which signals tell a cell to become specialized, and how other cells remain multipotent.

**Potential Benefits** Basic research on stem cells takes on a special urgency in light of the importance it might have for human health. There are many causes of damage to particular types of cells. Heart attacks destroy cells in the heart muscle, strokes injure brain cells, and spinal cord injuries cause paralysis by breaking connections between nerve cells. Given the suffering and death caused by these conditions, the prospect of using stem cells to repair such cellular damage has excited medical researchers.

Many hope to see a day when the damage caused by a severe heart attack can be reversed using stem cell therapy. Experiments using animals suggest that several approaches show promise of success. One approach might be to inject stem cells from the patient’s bone marrow into the heart’s damaged area, as shown in Figure 10–21. Another approach is to inject embryonic stem cells that might eventually differentiate into new heart muscle cells. **Stem cells offer the potential benefit of using undifferentiated cells to repair or replace badly damaged cells and tissues.**
**Ethical Issues** Because adult stem cells can be obtained directly from the body of a willing donor, research with these cells has raised few ethical questions to date. This is not the case with embryonic stem cells, which are generally obtained from very early embryos.

Most techniques for harvesting embryonic stem cells cause the destruction of an embryo. For this reason, individuals who regard the embryo as entitled to the rights and protections of any human being object to such work. This concern has made government funding of embryonic stem cell research an important political issue. Groups seeking to protect embryos oppose such research as unethical. Other groups support such research as essential for saving human lives and argue that it would be unethical to restrict research. **Human embryonic stem cell research is controversial because the arguments for it and against it both involve ethical issues of life and death.**

It is possible, however, that in the not-too-distant future, both ethical concerns will be addressed with a technological solution. Some recent experiments have suggested that there may be ways to extract a small number of stem cells from an early embryo without damaging the embryo itself. Other experiments have shown that it is possible to switch “on” a small number of genes that reprogram adult cells to look and function like pluripotent embryonic stem cells. Such a technique would do away with the need to involve embryos at all. It also might make it possible to tailor specific therapies to the needs of each individual patient. Approaches like these, if successful, might allow potentially lifesaving research to go forward while avoiding any destruction of embryonic life.

**In Your Notebook** Make a two-column chart that lists the benefits and issues related to stem cell research.

**10.4 Assessment**

**Review Key Concepts**

1. **a. Review** What happens during differentiation?
   
   **b. Apply Concepts** What does “mapping” refer to in the process of cell differentiation?

2. **a. Review** What are stem cells?
   
   **b. Compare and Contrast** How are embryonic stem cells and adult stem cells alike? How are they different?

3. **a. Review** Summarize the potential benefits and issues of stem cell research.
   
   **b. Form an Opinion** How might technological advances help address the ethical concerns surrounding stem cell research?

**Apply the Big Idea**

**Cellular Basis of Life**

4. Use what you learned in this lesson to discuss how cells become specialized for different functions. Include an explanation of how the potential for specialization varies with cell type and how it varies over the life span of an organism.
Pre-Lab: Regeneration in Planaria

**Problem**  How potent are the stem cells in planaria?

**Materials**  fresh water or spring water, planarians, petri dishes, grease pencil, forceps, scalpel, dissecting microscope, glass microscope slide, lens paper, pipette, small paintbrush, clear ruler

**Lab Manual**  Chapter 10 Lab

**Skills Focus**  Form a Hypothesis, Design an Experiment, Draw Conclusions

**Connect to the Big idea**  All cells come from existing cells. When most cells in a multicellular organism divide, they produce cells just like themselves. However, some cells can differentiate to form different types of cells. These cells enable an organism to repair tissue after an injury or in some cases to regenerate body parts. In this lab, you will investigate the ability of planarians to regenerate body parts.

**Background Questions**

a. **Compare and Contrast**  What is the difference between totipotent stem cells and multipotent stem cells?

b. **Apply Concepts**  What type of stem cell enables your body to produce cells, such as skin and blood cells that are constantly replaced by the body?

c. **Apply Concepts**  What type of stem cell enables a salamander to regenerate its tail?

d. **Compare and Contrast**  In what way is regeneration of a body part similar to asexual reproduction? In what way is it different?

**Pre-Lab Questions**

*Preview the procedure in the lab manual.*

1. **Apply Concepts**  What would you expect to observe if the stem cells in planarians are totipotent? What would you expect to observe if the stem cells are multipotent?

2. **Control Variables**  What will you use as a control in your experiment? Explain why you need this control.

3. **Infer**  Two planarians are cut at different locations. Regeneration occurs in one planarian, but not in the other. Based on these results, what might you infer about stem cells in planarians?

---

Visit Chapter 10 online to test yourself on chapter content and to find activities to help you learn.

**Untamed Science Video**  Journey with the Untamed Science crew to a research facility in Sweden to learn why scientists are studying regeneration in brittle stars.

**Visual Analogy**  Compare a growing cell to a growing city to understand limits on cell size.

**Data Analysis**  Learn how to time the cell cycle by counting cells in mitosis.

**Art Review**  Test your knowledge of the structure of a eukaryotic chromosome.

**InterActive Art**  See the phases of mitosis in action.

**Art in Motion**  See what happens when cancerous cells invade normal tissue.
Cells undergo cell division to produce new cells. In eukaryotic cells, cell division is part of a highly regulated cycle known as the cell cycle.

**10.1 Cell Growth, Division, and Reproduction**

- The larger a cell becomes, the more demands the cell places on its DNA. In addition, a larger cell is less efficient in moving nutrients and waste materials across the cell membrane.
- Asexual reproduction is the production of genetically identical offspring from a single parent.
- Offspring produced by sexual reproduction inherit some of their genetic information from each parent.

**10.2 The Process of Cell Division**

- Chromosomes make it possible to separate DNA precisely during cell division.
- During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells.
- During prophase, the genetic material inside the nucleus condenses. During metaphase, the chromosomes line up across the center of the cell. During anaphase, the chromosomes separate and move along spindle fibers to opposite ends of the cell. During telophase, the chromosomes, which were distinct and condensed, begin to spread out into a tangle of chromatins.
- Cytokinesis completes the process of cell division—it splits one cell into two.

**10.3 Regulating the Cell Cycle**

- The cell cycle is controlled by regulatory proteins both inside and outside the cell.
- Cancer cells do not respond to the signals that regulate the growth of most cells. As a result, the cells divide uncontrollably.

**10.4 Cell Differentiation**

- During the development of an organism, cells differentiate into many types of cells.
- The unspecialized cells from which differentiated cells develop are known as stem cells.
- Stem cells offer the potential benefit of using undifferentiated cells to repair or replace badly damaged cells and tissues.
- Human embryonic stem cell research is controversial because the arguments for it and against it both involve ethical issues of life and death.

**Think Visually** Using the information in this chapter, complete the following cycle diagram of the cell cycle.

1. The chromatin condenses into chromosomes.
2. The chromosomes gather at opposite ends of the cell.
3. Cytokinesis completes the process of cell division.
4. Interphase (281)
10.1 Cell Growth, Division, and Reproduction

Understand Key Concepts
1. The rate at which materials enter and leave the cell depends on the cell’s
   a. volume.    c. speciation.
   b. weight.    d. surface area.

2. In order for a cell to divide successfully, the cell must first
   a. duplicate its genetic information.
   b. decrease its volume.
   c. increase its number of chromosomes.
   d. decrease its number of organelles.

3. The process that increases genetic diversity within a population is
   a. asexual reproduction.    c. cell division.
   b. sexual reproduction.    d. binary fission.

4. Describe what is meant by each of the following terms: cell volume, cell surface area, ratio of surface area to volume.

5. Describe asexual and sexual reproduction as survival strategies.

Think Critically
6. Calculate Calculate the ratio of surface area to volume of an imaginary cubic cell measuring 4 mm long on each side.

7. Form a Hypothesis In a changing environment, which organisms have an advantage—those that reproduce asexually or those that reproduce sexually? Explain your answer.

10.2 The Process of Cell Division

Understand Key Concepts
8. Sister chromatids are attached to each other at an area called the
   a. centriole.    c. centromere.
   b. spindle.    d. chromosome.

9. If a cell has 12 chromosomes, how many chromosomes will each of its daughter cells have after mitosis and cytokinesis?
   a. 4    b. 6    c. 12    d. 24

10. Which of the illustrations below best represents metaphase of mitosis?

11. In plant cells, what forms midway between the divided nuclei during cytokinesis?
   a. nuclear membrane    c. cell membrane
   b. centromere    d. cell plate

12. Describe how a eukaryotic cell’s chromosomes change as a cell prepares to divide.

13. What is the relationship between interphase and cell division?

14. List the following stages of mitosis in the correct sequence, and describe what happens during each stage: anaphase, metaphase, prophase, and telophase.

Think Critically
15. Compare and Contrast How is the process of cell division in prokaryotes different from cell division in eukaryotes?

16. Form a Hypothesis Some cells have several nuclei within their cytoplasm. Considering the events in a typical cell cycle, which phase of the cell cycle is not operating when such cells form?

17. Compare and Contrast Describe the differences between cell division in an animal cell and cell division in a plant cell.

18. Relate Cause and Effect The nerve cells in the human nervous system seldom undergo mitosis. Based on this information, explain why complete recovery from injuries to the nervous system usually does not occur.

19. Apply Concepts A scientist treats cells with a chemical that prevents DNA synthesis. In which stage of the cell cycle will these cells remain?
20. **Interpret Visuals** The diagram shows a phase of mitosis. Use the diagram to answer the following questions.

a. Identify the phase of mitosis shown in the diagram.
b. Is this a plant or animal cell? How do you know?
c. The four chromosomes shown in the center of this cell each have two connected strands. Explain how the two strands on the same chromosome compare with regard to the genetic information they carry. In your answer, be sure to explain why this is important to the cell.

### 10.3 Regulating the Cell Cycle

**Understand Key Concepts**

21. The timing in the cell cycle in eukaryotic cells is believed to be controlled by a group of closely related proteins known as
   a. chromatids.
   b. cyclins.
   c. centromeres.
   d. centrioles.

22. In the cell cycle, external regulatory proteins direct cells to
   a. speed up or slow down the cell cycle.
   b. remain unchanged.
   c. proceed and then stop the cell cycle.
   d. grow uncontrollably.

23. When some cells are removed from the center of a tissue culture, will new cells replace the cells that were removed? Explain.

24. Describe the role of cyclins.

**Think Critically**

25. **Compare and Contrast** How do cancer cells differ from noncancerous cells? How are they similar?

26. **Predict** A cell will usually undergo apoptosis if the cell experiences DNA damage that could lead to a tumor. Predict what may happen if a gene that controls apoptosis is damaged.

### PET SHOP ACCIDENT

**Week 1: Dedifferentiation**

At first, cells in the injured limb undergo dedifferentiation. During this process, cells such as muscle cells and nerve cells lose the characteristics that make them specialized.

**Week 3: Blastema Formation**

The dedifferentiated cells migrate to the wounded area and form a blastema—a growing mass of undifferentiated cells.

**Week 5: Redifferentiation**

Cells in the blastema then redifferentiate and form the tissues needed for a mature limb. The limb will continue to grow until it is full size.

1. **Relate Cause and Effect** Why is dedifferentiation of the salamander’s limb cells necessary before regeneration can occur?

2. **Classify** What type of cells do you think are contained in the blastema? Explain.

3. **Connect to the Big idea** Unlike salamanders, planarians contain undifferentiated cells throughout their adult bodies. How might the regeneration process in salamanders and planarians differ?
10.4 Cell Differentiation

Understand Key Concepts

27. Bone marrow cells that produce blood cells are best categorized as
   a. embryonic stem cells.  c. pluripotent.
   b. adult stem cells.  d. totipotent cells.

28. Which type of cell has the potential to develop into any type of cell?
   a. totipotent  c. multipotent
   b. pluripotent  d. differentiated

29. What is a blastocyst?

30. What is cell differentiation and how is it important to an organism’s development?

31. Describe two ways that technology may address the ethical concerns related to stem cell research.

Think Critically

32. Relate Cause and Effect When researchers discovered how to make skin stem cells pluripotent, how did they apply their discovery to the treatment for heart attack patients?

33. Compare and Contrast How does embryonic development and cell differentiation in C. elegans differ from how these processes work in mammals?

Use Science Graphics

Use the data table to answer questions 34 and 35.

<table>
<thead>
<tr>
<th>Life Spans of Various Human Cells</th>
<th>Cell Type</th>
<th>Life Span</th>
<th>Cell Division</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red blood cells</td>
<td>&lt;120 days</td>
<td>Cannot divide</td>
<td></td>
</tr>
<tr>
<td>Cardiac (heart) muscle</td>
<td>Long-lived</td>
<td>Cannot divide</td>
<td></td>
</tr>
<tr>
<td>Smooth muscle</td>
<td>Long-lived</td>
<td>Can divide</td>
<td></td>
</tr>
<tr>
<td>Neuron (nerve cell)</td>
<td>Long-lived</td>
<td>Most do not divide</td>
<td></td>
</tr>
</tbody>
</table>

34. Compare and Contrast Based on the data, in what ways might injuries to the heart and spinal cord be similar? How might they differ from injuries to smooth muscles?

35. Predict If cancer cells were added to the table, predict what would be written in the Life Span and Cell Division columns. Explain.

Write About Science

36. Explanation Recall what you learned about the characteristics of life in Chapter 1. Explain how cell division is related to two or more of those characteristics.

37. Assess the Big Idea How is cancer an example of how changes to a single cell can affect the health of an entire organism?

38. Interpret Tables On the basis of the data in the table, how long would you expect the cell cycle to be at 5°C?
   a. less than 13.3 hours  
   b. more than 54.6 hours  
   c. between 29.8 and 54.6 hours  
   d. about 20 hours

39. Draw Conclusions Given this set of data, what is one valid conclusion the scientist could state?
Multiple Choice

1. Which statement is true regarding a cell’s surface area-to-volume ratio?
   A. As the size of a cell increases, its volume decreases.
   B. As the size of a cell decreases, its volume increases.
   C. Larger cells will have a greater surface area-to-volume ratio.
   D. Smaller cells will have a greater surface area-to-volume ratio.

2. Which of the following is NOT an advantage of asexual reproduction?
   A. simple and efficient
   B. produces large number of offspring quickly
   C. increases genetic diversity
   D. requires one parent

3. At the beginning of cell division, a chromosome consists of two
   A. centromeres
   B. centrioles
   C. chromatids
   D. spindles

4. What regulates the timing of the cell cycle in eukaryotes?
   A. chromosomes
   B. cyclins
   C. nutrients
   D. DNA and RNA

5. The period between cell divisions is called
   A. interphase
   B. prophase
   C. G3 phase
   D. cytokinesis

6. Which of the following is TRUE about totipotent cells?
   A. Embryonic stem cells are totipotent cells.
   B. Totipotent cells are differentiated cells.
   C. Totipotent cells can differentiate into any type of cell and tissue.
   D. Adult stem cells are totipotent cells.

7. A cell enters anaphase before all of its chromosomes have attached to the spindle. This may indicate that the cell is not responding to
   A. internal regulators
   B. mitosis
   C. growth factors
   D. apoptosis

Questions 8–10

The spindle fibers of a dividing cell were labeled with a fluorescent dye. At the beginning of anaphase, a laser beam was used to mark a region of the spindle fibers about halfway between the centrioles and the chromosomes. The laser beam stopped the dye from glowing in this region, as shown in the second diagram. The laser did not inhibit the normal function of the fibers.

8. This experiment tests a hypothesis about
   A. how chromosomes migrate during cell division.
   B. how fluorescent dyes work in the cell.
   C. the effect of lasers on cells.
   D. why cells divide.

9. The diagrams show that chromosomes move to the poles of the cell as the spindle fibers
   A. shorten on the chromosome side of the mark.
   B. lengthen on the chromosome side of the mark.
   C. shorten on the centriole side of the mark.
   D. lengthen on the centriole side of the mark.

10. A valid conclusion that can be drawn from this experiment is that the spindle fibers break down
    A. at the centrioles.
    B. in the presence of dye.
    C. when marked by lasers.
    D. where they are attached to chromosomes.

Open-Ended Response

11. Explain why careful regulation of the cell cycle is important to multicellular organisms.

If You Have Trouble With . . .

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>See Lesson</td>
<td>10.1</td>
<td>10.1</td>
<td>10.2</td>
<td>10.3</td>
<td>10.2</td>
<td>10.4</td>
<td>10.3</td>
<td>10.2</td>
<td>10.2</td>
<td>10.2</td>
<td>10.3</td>
</tr>
</tbody>
</table>
Unit Project

Superhero Cell

Do you like reading comics? Have you ever designed a comic book of your own? Here’s your chance! A high school teacher has contacted you asking for a comic book on cells and cell processes. She has told you that her students are just about to start studying cells and need a good introduction to the topic. You’ve been tasked with developing the story line and visuals that will provide the students with a basic understanding of cell structure and function. Remember that sometimes a picture can be worth a thousand words—so be creative!

Your Task  Write a comic book about a “superhero cell” for an audience of high school students.

Be sure to
• incorporate important concepts and details about the structure and function of various organelles and cell processes.
• provide insight into the ways cells work and interact with their environment.
• be entertaining and creative.

Reflection Questions
1. Score your project using the rubric below. What score did you give yourself?
2. What did you do well on this project?
3. What about your project needs improvement?
4. Exchange your comic book with a classmate and have him/her read it. What did your partner like about your comic book? What did he/she think could use improvement?

Assessment Rubric

<table>
<thead>
<tr>
<th>Score</th>
<th>Scientific Content</th>
<th>Quality of Comic Book</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>The comic book includes accurate details about the structures and functions of several organelles and cell processes. It provides exceptional insight into how a cell works and interacts with its environment.</td>
<td>The comic book is thoughtfully and creatively written and illustrated.</td>
</tr>
<tr>
<td>3</td>
<td>The comic book includes mostly accurate details about the structure and functions of organelles and cell processes. It provides good insight into how a cell works and interacts with its environment.</td>
<td>The comic book is well written and includes some creativity. Illustrations are clear.</td>
</tr>
<tr>
<td>2</td>
<td>The comic book includes a few details about the structure and functions of organelles and cell processes, with some inaccuracies. It provides some insight into how a cell works and interacts with its environment.</td>
<td>The comic book needs some edits and could use more creativity. Some parts of the story line and illustrations are difficult to follow.</td>
</tr>
<tr>
<td>1</td>
<td>The comic book includes vague and inaccurate information about the structure and functions of organelles and cell processes. It provides little insight into how a cell works and interacts with its environment.</td>
<td>The comic book needs significant edits and includes very little creativity. Story line and illustrations are unclear.</td>
</tr>
</tbody>
</table>
Dear Colleague,

A few months ago, I had the honor of speaking at a symposium in honor of Gregor Mendel. To prepare for my talk for the meeting, I read over Mendel’s famous paper, a dry scientific report with the unassuming title of “Investigations of Plant Hybridization.” As I turned the pages, I wondered if Mendel himself had any idea what he was starting. It would take decades, of course, but eventually his work led to a revolution in biology. Once, we naturalists were merely observers of life. Biologists today, of course, are active participants who study, shape, analyze, and even change living things.

What struck me most as I looked over Mendel’s paper was not the way in which it laid out the basic principles of genetics. Mendel’s great contribution, it seems to me, was his insistence that life itself could be studied, analyzed, and understood along systematic, rational lines. This attitude infuses every paragraph of his work, and it was picked up, almost unconsciously, by the scientists who rediscovered and extended that work at the beginning of the twentieth century.

Today, we have an opportunity to bring that sense of discovery to our students as never before. The rise of Mendelian genetics led to intense curiosity about the chemical nature of the gene. That, in turn, led to the identification of DNA as the genetic material, as well as the discovery of its double-helical structure. The result of all that curiosity, of course, is a new understanding of life that we can bring to all of our students. DNA carries the genetic code, and with it the fundamental instructions that operate our cells and interact with the environment to build our bodies. It’s both our heritage and the legacy that we pass along to new generations. It’s also something we share with every other living thing on this planet. That revolution in understanding may have begun with Gregor Mendel, but it hasn’t stopped, even today. Indeed, the most important message we may be able to give our students is that the really interesting work is just beginning.
Introduction to Genetics

Information and Heredity

Q: How does biological information pass from one generation to another?

Connect to the Big Idea

Have students look at the photo and describe their observations. Ask students whether they think the dogs in the photo are related to one another. (Students might say that they are all the same breed, so they could be from the same family.) Explain that the colors of the dogs’ coats are determined by heredity, or the passing of traits from parents to offspring. Then, have students read the question, How does biological information pass from one generation to another? Tell students that, in this chapter, they will learn how offspring can inherit information from both parents, yet show traits that do not appear in either parent.

Have students read over the Chapter Mystery and brainstorm a list of reasons why none of the chicks look like their parents. As a hint, suggest students reread the chapter’s Big Idea and Essential Question. Have students refer back to this list as they gather more evidence throughout the chapter.

Have students preview the chapter vocabulary using the Flash Cards.

Understanding by Design

In Chapter 11, students discover how cellular information passes from one generation to another. The graphic organizer at right shows how chapter content frames their exploration of the Unit 4 Enduring Understanding: DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

PERFORMANCE GOALS

In Chapter 11, students are introduced to many basic genetics concepts. Lesson assessments provide real-life genetics problems for students to solve using their knowledge of chapter concepts. At the end of the chapter, students will complete assessment tasks that require creative writing and critical thinking skills to synthesize knowledge of meiosis, patterns of inheritance, and gene linkage.
Chapter 11

Chapter 11 Big Idea:
Information and Heredity

Chapter 11 EQ:
How does cellular information pass from one generation to another?

11.1 GQ: How does an organism pass its characteristics on to its offspring?

11.2 GQ: How can you predict the outcome of a genetic cross?

11.3 GQ: How can interactions between alleles, genes, and the environment affect an organism’s traits?

11.4 GQ: How does a cell divide to create cells with exactly half of the original cell’s genetic information?

What’s Online

Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
As students delve into the principles of heredity, they uncover clues that help them solve the seeming paradox of yellow, blue, and white offspring from green parents.

UNTAMED SCIENCE VIDEO
Take a trip back in time with the Untamed Science crew in Genetics Takes Root to see Mendel in action.

INTERACTIVE ART
Students can use this interactive activity to learn more about Punnett squares.

ART REVIEW
Students can use this drag-and-drop activity to review inheritance patterns using Punnett squares.

ART IN MOTION
This short animation shows students how genetic material is separated during meiosis.

TUTOR TUBE
To help students better understand the process of meiosis, the tutor makes connections between meiosis and Punnett squares.

DATA ANALYSIS
Students analyze the connection between crossing-over and gene location.

GREEN PARAKEETS
Susan’s birthday was coming up. Parakeets make great pets, so Susan’s parents decided to give two birds to her as a birthday present. At the pet store, they selected two healthy green parakeets—one male and one female. They knew that green was Susan’s favorite color.

Susan was delighted about her birthday present. She fed the birds and kept their cage clean. A few weeks later, Susan found three small eggs in the birds’ nest. She couldn’t wait to welcome three new green parakeets. When the eggs finally hatched, however, Susan was amazed. None of the chicks was green—one chick was white, one was blue, and one was yellow. Why weren’t any of them green? What had happened to the green color of the birds’ parents? As you read this chapter, look for clues to help you identify why the parakeet chicks were differently colored than their parents. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the green parakeet mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

INTRODUCTION TO GENETICS
Getting Started

Objectives
11.1.1 Describe Mendel’s studies and conclusions about inheritance.
11.1.2 Describe what happens during segregation.

Student Resources
Study Workbook A and B, 11.1 Worksheets
Spanish Study Workbook, 11.1 Worksheets

Build Background
Show students a picture of a large family that includes at least two generations. Ask students to list some physical characteristics that the younger family members likely inherited from their parents or grandparents. Invite volunteers to share one or two items on their list. Then, encourage students to share their ideas about the inheritance of traits.

The Work of Gregor Mendel

THINK ABOUT IT What is an inheritance? To many people, it is money or property left to them by relatives who have passed away. That kind of inheritance matters, of course, but there is another kind that matters even more. It is something we each receive from our parents—a contribution that determines our blood type, the color of our hair, and so much more. Most people leave their money and property behind by writing a will. But what kind of inheritance makes a person’s face round or their hair curly?

The Experiments of Gregor Mendel

Every living thing—plant or animal, microbe or human being—has a set of characteristics inherited from its parent or parents. Since the beginning of recorded history, people have wanted to understand how that inheritance is passed from generation to generation. The delivery of characteristics from parent to offspring is called heredity. The scientific study of heredity, known as genetics, is the key to understanding what makes each organism unique.

The modern science of genetics was founded by an Austrian monk named Gregor Mendel. Mendel, shown in Figure 11–1, was born in 1822 in what is now the Czech Republic. After becoming a priest, Mendel spent several years studying science and mathematics at the University of Vienna. He spent the next 14 years working in a monastery and teaching high school. In addition to his teaching duties, Mendel was in charge of the monastery garden. In this simple garden, he was to do the work that changed biology forever.

Mendel carried out his work with ordinary garden peas, partly because peas are small and easy to grow. A single pea plant can produce hundreds of offspring. Today we call peas a “model system.” Scientists use model systems because they are convenient to study and may tell us how other organisms, including humans, actually function. By using peas, Mendel was able to carry out, in just one or two growing seasons, experiments that would have been impossible to do with humans and that would have taken decades—if not centuries—to do with pigs, horses, or other large animals.

FIGURE 11–1 Gregor Mendel

Teach for Understanding

ENDURING UNDERSTANDING DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION How does an organism pass its characteristics on to its offspring?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how Gregor Mendel contributed to our knowledge of how an organism passes its characteristics on to its offspring. Have each student write a short story about Mendel’s experiments using the first person point of view, as if Gregor Mendel was writing the story himself. Tell them that their stories should clearly explain Mendel’s experiments and his conclusions.
**The Role of Fertilization** When Mendel began his experiments, he knew that the male part of each flower makes pollen, which contains the plant’s male reproductive cells, called sperm. Similarly, Mendel knew that the female portion of each flower produces reproductive cells called eggs. During sexual reproduction, male and female reproductive cells join in a process known as fertilization to produce a new cell. In peas, this new cell develops into a tiny embryo encased within a seed.

Pea flowers are normally self-pollinating, which means that sperm cells fertilize egg cells from within the same flower. A plant grown from a seed produced by self-pollination inherits all of its characteristics from the single plant that bore it; it has a single parent.

Mendel’s monastery garden had several stocks of pea plants. These plants were “true-breeding,” meaning that they were self-pollinating, and would produce offspring identical to themselves. In other words, the traits of each successive generation would be the same. A trait is a specific characteristic, such as seed color or plant height, of an individual. Many traits vary from one individual to another. For instance, one stock of Mendel’s seeds produced only tall plants, while another produced only short ones. One line produced only green seeds, another produced only yellow seeds.

To learn how these traits were determined, Mendel decided to “cross” his stocks of true-breeding plants—that is, he caused one plant to reproduce with another plant. To do this, he had to prevent self-pollination. He did so by cutting away the pollen-bearing male parts of a flower. He then dusted the pollen from a different plant onto the female part of that flower, as shown in Figure 11–2. This process, known as cross-pollination, produces a plant that has two different parents. Cross-pollination allowed Mendel to breed plants with traits different from those of their parents and then study the results.

Mendel studied seven different traits of pea plants. Each of these seven traits had two contrasting characteristics, such as green seed color or yellow seed color. Mendel crossed plants with each of the seven contrasting characteristics and then studied their offspring. The offspring of crosses between parents with different traits are called hybrids.

**In Your Notebook** Explain, in your own words, what fertilization is.

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**How Science Works**

**METHODS OF MENDEL’S SUCCESS**

Mendel was the first scientist of his time to obtain successful results from inheritance studies because of the methods he employed. He studied only one trait at a time. He also took the time to verify that the parent plants were true-breeding for the particular trait he was studying. He used a quantitative approach to analyze his results. He counted the number of offspring from every cross and used statistical analysis to interpret his numbers. Most important, Mendel formulated hypotheses to explain his results, and he developed experimental tests to support them. Many of his methods were so successful that they continue to be used today.

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**Answers**

**FIGURE 11–2** The flower with the female part intact no longer had its own source of pollen.

**IN YOUR NOTEBOOK** Explanations should include that male and female reproductive cells join to form a new cell.
LESSON 11.1

Teach continued

Use Visuals

Use Figure 11–3 to review the different forms of each trait in the peas Mendel studied. Explain that the traits in pea plants have two distinct forms. Direct students’ attention to the trait of seed shape.

Ask What does it mean for the trait of roundness to be dominant in the F₁ generation? (If a plant has one allele for round and one for wrinkled, the offspring will have a round seed shape.)

DIFFERENTIATED INSTRUCTION

Special Needs Check that students understand the symbols P and F₁ in Figure 11–3. Then, explain that the symbol x stands for “cross,” and point out the example of a round-seeded plant crossed with a wrinkle-seeded plant. Draw the chart on the board in a new orientation with Trait, Parent 1, Parent 2, and Offspring as column heads. Start filling in the chart by writing x between Parent 1 and Parent 2 and → between Parent 2 and Offspring. Write “seed shape” under Trait, “round” under Parent 1, “wrinkled” under Parent 2, and “round” under Offspring. Have students complete the chart in this way for the rest of the traits from Figure 11–3.

Focus on ELL: Access Content

ALL SPEAKERS Model how a recessive allele can be masked by a dominant allele. Start by tapping both of your pointer fingers on your desktop. Tell students that a tapping finger models the expression of a dominant allele. The recessive allele for this trait is modeled by a silent, still finger. Show two fingers tapping, for homozygous dominant, and then two still fingers, for homozygous recessive. Then, tap one finger while keeping the other still. Point out that you can still hear tapping, or the dominant allele, even though only one finger is moving. Suggest pairs of students come up with their own models of dominance. Then, have each pair share their model with the class.

Remind students that an allele is one form of a gene. Then, have them make predictions about the number of alleles there might be for feather color. Guide them to conclude that there is likely more than two alleles since there are four possible phenotypes. Students can go online to Biology.com to gather their evidence.

Genes and Alleles When doing genetic crosses, we call each original pair of plants the P, or parental, generation. Their offspring are called the F₁, or first filial, generation. (Filius and filia are the Latin words for “son” and “daughter.”)

What were Mendel’s F₁ hybrid plants like? To his surprise, for each trait studied, all the offspring had the characteristics of only one of its parents, as shown in Figure 11–3. In each cross, the nature of the other parent, with regard to each trait, seemed to have disappeared. From these results, Mendel drew two conclusions. His first conclusion formed the basis of our current understanding of inheritance.

An individual’s characteristics are determined by factors that are passed from one parental generation to the next. Today, scientists call the factors that are passed from parent to offspring genes.

Each of the traits Mendel studied was controlled by a single gene that occurred in two contrasting varieties. These variations produced different expressions, or forms, of each trait. For example, the gene for plant height occurred in one form that produced tall plants and in another form that produced short plants. The different forms of a gene are called alleles (uh LEElz).

Dominant and Recessive Alleles Mendel’s second conclusion is called the principle of dominance. This principle states that some alleles are dominant and others are recessive. An organism with at least one dominant allele for a particular form of a trait will exhibit that form of the trait. An organism with a recessive allele for a particular form of a trait will exhibit that form only when the dominant allele for the trait is not present. In Mendel’s experiments, the allele for tall plants was dominant and the allele for short plants was recessive. Likewise, the allele for yellow seeds was dominant over the recessive allele for green seeds.

Check for Understanding

QUESTION BOX

Establish a question box or email address where students may post questions about the concepts in this lesson they do not understand. Collect the questions at the end of each class session and review them. At the beginning of the next class session, discuss the questions and answers with the class.

ADJUST INSTRUCTION

If several students are having difficulty understanding a concept, set up small study groups that each include at least one student who understands the material and can communicate well with other members. Have groups meet for a few minutes at the beginning or end of class to go over difficult concepts.
Classroom Variation
1. Copy the data table into your notebook.
2. Write a prediction of whether the traits listed in the table will be evenly distributed or if there will be more dominant than recessive traits.
3. Examine your features, using a mirror if necessary. Determine which traits you have for features A–E.
4. Interview at least 14 other students to find out which traits they have. Tally the numbers. Record the totals in each column.

Analyze and Conclude
1. **Calculate** Calculate the percentages of each trait in your total sample. How do these numbers compare to your prediction?

**Segregation**

**How are different forms of a gene distributed to offspring?**

Mendel didn’t just stop after crossing the parent plants, because he had another question: Had the recessive alleles simply disappeared, or were they still present in the new plants? To find out, he allowed all seven kinds of F₁ hybrids to self-pollinate. The offspring of an F₁ cross are called the F₂ (second filial) generation. In effect, Mendel crossed the F₁ generation with itself to produce the F₂ offspring, as shown in Figure 11–4.

**The F₁ Cross** When Mendel compared the F₁ plants, he made a remarkable discovery: The traits controlled by the recessive alleles reappeared in the second generation. Roughly one fourth of the F₂ plants showed the trait controlled by the recessive allele. Why, then, did the recessive alleles seem to disappear in the F₁ generation, only to reappear in the F₂ generation?

**Figure 11–4** Results of the F₂ Cross. When Mendel allowed the F₁ plants to reproduce by self-pollination, the traits controlled by recessive alleles reappeared in about one fourth of the F₂ plants in each cross.

<table>
<thead>
<tr>
<th>Trait Survey</th>
<th>Feature</th>
<th>Dominant Trait</th>
<th>Number</th>
<th>Recessive Trait</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Free ear lobes</td>
<td></td>
<td>Attached ear lobes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B Hair on fingers</td>
<td></td>
<td>No hair on fingers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Widow’s peak</td>
<td></td>
<td>No widow’s peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Curly hair</td>
<td></td>
<td>Straight hair</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E Cleft chin</td>
<td></td>
<td>Smooth chin</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. **Form a Hypothesis** Why do you think recessive traits are more common in some cases?

**Use Visuals**

Walk students through the crosses shown in Figure 11–4. Make sure they understand that the short trait reappeared because the F₁ generation had both tall and short alleles.

**Ask** Why didn’t the allele for shortness show in the F₁ generation? (The short allele is recessive. It was masked by the dominant allele for tallness.)

**Ask** Was the recessive allele for shortness lost in the F₁ generation? How do you know? (No, it reappeared in the F₂ generation.)

**DIFFERENTIATED INSTRUCTION**

**Less Proficient Readers** Help struggling readers make connections between the text and Figure 11–4. Explain that the text on this page focuses primarily on the bottom two parts of the figure. Have student volunteers read the text on the page a couple of sentences at a time. After each volunteer finishes reading, discuss how the text he or she just read is shown by or relates to Figure 11–4.

**Advanced Students** Challenge students to create a poster on which they identify Mendel’s question and hypothesis and outline his experimental design.

**Quick Lab**

**PURPOSE** Students will make a prediction about whether dominant traits are more common than recessive traits and form a hypothesis about why recessive traits are more common in some cases.

**MATERIALS** mirror (optional)

**SAFETY** Caution students to handle glass mirrors with care.

**PLANNING** Bring mirrors to class, or invite students to bring mirrors from home. Tell students the traits shown by the class may vary from a larger population because of the small sample size.

**ANALYZE AND CONCLUDE**

1. **Results and predictions will vary.** Sample prediction: Dominant traits are more common than recessive traits. Results will likely indicate that a dominant trait is not necessarily more common than a recessive one.

2. **Sample answer:** Recessive alleles may be more common in the population.

**Figure 11–4** Three-fourths of the F₂ plants had a trait controlled by a dominant allele.

**In Your Notebook** Students’ diagrams should have content similar to that in Figure 11–3.
Assess and Remediate

EVALUATE UNDERSTANDING
Assign students a trait in pea plants from Figure 11–3. Have them set up a cross to show the hybrid F1 and resulting F2 offspring. Then, have them complete the 11.1 Assessment.

REMEDIATION SUGGESTION
Struggling Students If your students have trouble with Question 2b, choose a pea trait from Figure 11–3 besides height. Draw the alleles and gametes for the P generation through the F1 and F2 generations. Walk through each step, using the terms dominant, recessive, allele, gamete, and segregation.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers
1a. factors that are passed from one generation to the next
1b. dominant: form of an allele whose trait always shows up if it is present; recessive: form of an allele whose trait shows up only when the dominant allele is not present
1c. They have two identical alleles for a gene, so in a genetic cross, each parent contributes only one form of a gene, making inheritance patterns more detectable.
2a. separation of alleles
2b. The two alleles of the P generation separate during gamete formation. Each gamete carries only a single allele from each parent, which pairs at random in the F1 generation. The process repeats when F1 plants cross and produce F2 plants. As a result, the F2 generation has new combinations of alleles that may be different from those of preceding generations.
2c. A short plant appeared in the F1 generation, indicating that this plant had only recessive alleles, so the alleles in the F1 generation must have separated and then recombined when the plants were crossed.

Explaining the F1 Cross To begin with, Mendel assumed that a dominant allele had masked the corresponding recessive allele in the F1 generation. However, the trait controlled by the recessive allele did show up in some of the F2 plants. This reappearance indicated that, at some point, the allele for shortness had separated from the allele for tallness. How did this separation, or segregation, of alleles occur? Mendel suggested that the alleles for tallness and shortness in the F1 plants must have segregated from each other during the formation of the sex cells, or gametes (ga’methz). Did that suggestion make sense?

The Formation of Gametes Let’s assume, as Mendel might have, that all the F1 plants inherited an allele for tallness from the tall parent and one for shortness from the short parent. Because the allele for tallness is dominant, all the F1 plants are tall. During gamete formation, the alleles for each gene segregate from each other, so that each gamete carries only one allele for each gene. Thus, each F1 plant produces two kinds of gametes—those with the tall allele and those with the short allele.

Look at Figure 11–5 to see how alleles separate during gamete formation and then pair up again in the F2 generation. A capital letter represents a dominant allele. A lowercase letter represents a recessive allele. Now we can see why the recessive trait for height, t, reappeared in Mendel’s F2 generation. Each F1 plant in Mendel’s cross produced two kinds of gametes—those with the allele for tallness and those with the allele for shortness. Whenever a gamete that carried the t allele paired with the other gamete that carried the T allele to produce an F2 plant, that plant was short. Every time one or both gametes of the pairing carried the T allele, a tall plant was produced. In other words, the F2 generation had new combinations of alleles.

Visual Thinking
3. Diagrams should be similar to Figures 11–4 and 11–5 and clearly show single alleles, as well as which alleles are dominant and which are recessive.
THINK ABOUT IT. Nothing in life is certain. There's a great deal of wisdom in that old saying, and genetics is a fine example. If a parent carries two different alleles for a certain gene, we can't be sure which of those alleles will be inherited by any one of the parent's offspring. However, think carefully about the nature of inheritance and you'll see that even if we can't predict the exact future, we can do something almost as useful—we can figure out the odds.

Probability and Punnett Squares

How can we use probability to predict traits?

Whenever Mendel performed a cross with pea plants, he carefully categorized and counted the offspring. Consequently, he had plenty of data to analyze. For example, whenever he crossed two plants that were hybrids for stem height (Tt), about three fourths of the resulting plants were tall and about one fourth were short.

Upon analyzing his data, Mendel realized that the principles of probability could be used to explain the results of his genetic crosses. Probability is a concept you may have learned about in math class. It is the likelihood that a particular event will occur. As an example, consider an ordinary event, such as flipping a coin. There are two possible outcomes of this event: The coin may land either heads up or tails up. The chance, or probability, of either outcome is equal. Therefore, the probability that a single coin flip will land heads up is 1 chance in 2. This amounts to 1/2, or 50 percent.

If you flip a coin three times in a row, what is the probability that it will land heads up every time? Each coin flip is an independent event with a 1/2 probability of landing heads up. Therefore, the probability of flipping three heads in a row is:

\[ \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8} \]

As you can see, you have 1 chance in 8 of flipping heads three times in a row. The multiplication of individual probabilities illustrates an important point: Past outcomes do not affect future ones. Just because you've flipped three heads in a row does not mean that you're more likely to have a coin land tails up on the next flip. The probability for that flip is still 1/2.

FIGURE 11-6 Probability. Probability allows you to calculate the likelihood that a particular event will occur. The probability that the coin will land heads up is 1/2, or 50 percent.

Teach for Understanding

ENDURING UNDERSTANDING. DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism's characteristics.

GUIDING QUESTION. How can you predict the outcome of a genetic cross?

EVIDENCE OF UNDERSTANDING. After completing the lesson, give students the following assessment to show they understand how to predict the outcome of a genetic cross. Have students create a “how-to” book based on lesson concepts. Their books should explain how to apply the principles of probability to predict outcomes of genetic crosses as well as how to construct and use Punnett squares.

Getting Started

Objectives

11.2.1 Explain how geneticists use the principles of probability to make Punnett squares.
11.2.2 Explain the principle of independent assortment.
11.2.3 Explain how Mendel's principles apply to all organisms.

Student Resources

Study Workbook A and B, 11.2 Worksheets
Spanish Study Workbook, 11.2 Worksheets
Lab Manual A, 11.2 Quick Lab Worksheet
Lab Manual B, 11.2 Hands-On Activity

For corresponding lesson in the Foundation Edition, see pages 266–270.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

CONTENT

C.2.a, C.2.b, G.2

INQUIRY

A.1.b, A.1.c, A.2.a, A.2.b, A.2.d
**Teach**

**Connect to Math**

To explain how probability principles work in genetic crosses, model the cross shown in Figure 11–7. Write $Tt$ on the board, and draw a circle around it to represent the cell of one of the parents in the figure. Draw ten gamete circles under the parent cell. Then, draw an arrow from the parent cell to each gamete. To determine which allele ($T$ or $t$) will go in each gamete circle, flip a coin. Tell students that heads represents the dominant allele ($T$) and tails represents the recessive allele ($t$). As you fill in each circle, flip the coin and repeat that the probability of a $T$ or a $t$ going to a gamete is one in two, or $1/2$. Emphasize that each event is random and independent of the others and that probability predicts outcomes; it does not guarantee them. Then, do the same with another parent cell. Show two gametes joining, and explain that this event also is random and independent. Therefore, the probability of an $F_2$ cell having a particular combination of alleles is found by multiplying $1/2 \times 1/2$.

**DIFFERENTIATED INSTRUCTION**

- **LPR Less Proficient Readers** If students have trouble understanding the subsection Probabilities Predict Averages, have each student toss a coin 20 times and record the outcomes. Then, combine the data from the entire class. As you add in each student’s results, the overall data should get closer and closer to the expected ratio of one head to one tail.

**ELL Focus on ELL: Extend Language**

**BEGINNING, INTERMEDIATE, AND ADVANCED SPEAKERS** Have students construct a three-column chart to record lesson vocabulary terms and any other terms they may find difficult. Label column 1 Words I Understand, column 2 Words I Think I Understand, and column 3 Words I Have Never Seen. Ask students to write the definitions in their own words for columns 2 and 3. Allow beginning speakers to dictate their definitions as you record them. Intermediate and advanced speakers should write their own definitions. Use the information in the chart to focus ELL instruction.

**Answers**

**FIGURE 11–7** All of the offspring would be tall ($TT$ or $Tt$).

**Check for Understanding**

**HAND SIGNALS**

Focus students’ attention on Figure 11–7, and present them with the following statements. Ask them to show a thumbs-up sign if they understand, a thumbs-down sign if they are confused, or a waving-hand sign if they partially understand.

- A tall plant can be homozygous or heterozygous. A short plant must be homozygous.
- One-half of the $F_2$ generation is heterozygous and one-half is homozygous, but three-fourths are tall and one-fourth is short.

**ADJUST INSTRUCTION**

If students showed a thumbs-down or waving-hand sign, review the terms homozygous and heterozygous. Then, have small groups discuss why each statement is true.
Genotype and Phenotype  One of Mendel’s most revolutionary insights followed directly from his observations of F1 crosses: Every organism has a genetic makeup as well as a set of observable characteristics. All of the tall pea plants had the same phenotype, or physical traits. They did not, however, have the same genotype. Look again at Figure 11–7 and you will find three different genotypes among the F1 plants: TT, Tt, and tt. The genotype of an organism is inherited, and the phenotype is largely determined by the genotype. Two organisms may share the same phenotype but have different genotypes.

Using Punnett Squares  One of the best ways to predict the outcome of a genetic cross is by drawing a simple diagram known as a Punnett square. Punnett squares use mathematical probability to help predict the genotype and phenotype combinations in genetic crosses. Constructing a Punnett square is fairly easy. You begin with a square. Then, following the principle of segregation, all possible combinations of alleles in the gametes produced by one parent are written along the top edge of the square. The other parent’s alleles are then segregated along the left edge. Next, every possible genotype is written into the boxes within the square, just as they might appear in the F1 generation. Figure 11–8 on the next page shows step-by-step instructions for constructing Punnett squares.

How Are Dimples Inherited?

1. Write the last four digits of any telephone number. These four random digits represent the alleles of a gene that determines whether a person will have dimples. Odd digits represent the allele for the dominant trait of dimples. Even digits represent the allele for the recessive trait of no dimples.
2. Use the first two digits to represent a father’s genotype. Use the symbols D and d to write his genotype as shown in the example.

Father’s genotype is dd (2 even digits).
Mother’s genotype is Dd (1 even digit and 1 odd digit).

46 38

3. Use the last two digits the same way to find the mother’s genotype. Write her genotype.
4. Use Figure 11–8 on the next page to construct a Punnett square for the cross of these parents. Then, using the Punnett square, determine the probability that their child will have dimples.
5. Determine the class average of the percent of children with dimples.

Analyze and Conclude

1. Apply Concepts  How does the class average compare with the result of a cross of two heterozygous parents?
2. Draw Conclusions  What percentage of the children will be expected to have dimples if one parent is homozygous for dimples (DD) and the other is heterozygous (Dd)?

Tell students that having dimples is a dominant trait.

Analyze and Conclude

1. Answers will vary, but class averages usually will be close to the results of a cross of two heterozygous parents, that is, 75 percent of the children having dimples.
2. 100 percent will have dimples, because the allele for dimples is dominant.

Answers

IN YOUR NOTEBOOK  Sample answer: homozygous – an individual with two copies of the same allele of a gene; heterozygous – an individual with two different alleles for a gene; phenotype – the outward appearance of an individual; genotype – an individual’s genetic makeup.
LESSON 11.2

VISUAL SUMMARY

Use Figure 11–8 to help students learn how to construct, complete, and interpret a Punnett square. Walk them through the one-factor cross first. Have them identify the alleles each parent could pass on to offspring (BB and Bb). Walk through each column and row to make sure they understand how the alleles combine. Point out that combinations are simply pairings of the male and female alleles from a particular row and column. In step 5, remind students that a Punnett square identifies possible gene combinations and that actual combinations could be different. Then, call on volunteers to explain each step in the two-factor cross. Give the class practice problems in making and completing both types of Punnett squares.

DIFFERENTIATED INSTRUCTION

Struggling Students Students might need extra help figuring out the gametes in step 2 of the two-factor cross. Make sure they understand that each parent’s genotype includes two genes and that gametes get only one allele for each gene. Thus, for TTGg, there are two choices for height: T or t. No matter which of these go into a gamete, there are two choices for color: G or g. So the number of possible combinations is 4; 2 x 2 = 4. Tell students that one way to double-check their work in step 4 is to make sure the letter above each column appears in the cells below it. Similarly, the letter to the left of the rows must appear in each cell in that row.

English Language Learners As you describe each step, use vocabulary terms as often as possible. For example, in step 4, point out that in the completed table on the right, BB is homozygous dominant, bb is homozygous recessive, and Bb is heterozygous. Phrase questions so that students answer using vocabulary terms.

Students can learn more about Punnett squares in InterActive Art: Punnett Squares.

How Science Works

INVENTOR OF THE PUNNETT SQUARE

Reginald Punnett (1875–1967) was an English geneticist at Cambridge University who, along with William Bateson, was one of the first scientists to use Mendelian experimentation on plants and animals. Punnett devised the Punnett square to graphically represent the results of hybrid crosses. He also wrote a textbook on the subject of genetics and, together with Bateson, co-founded the Journal of Genetics, which is still in print today.
Independent Assortment

How do alleles segregate when more than one gene is involved?

After showing that alleles segregate during the formation of gametes, Mendel wondered if the segregation of one pair of alleles affects another pair. For example, does the gene that determines the shape of a seed affect the gene for seed color? To find out, Mendel followed two different genes as they passed from one generation to the next. Because it involves two different genes, Mendel’s experiment is known as a two-factor, or “dihybrid,” cross. (Single-gene crosses are “monohybrid” crosses.)

The Two-Factor Cross: F1

First, Mendel crossed true-breeding plants that produced only round yellow peas with plants that produced wrinkled green peas. The round yellow peas had the genotype RRYy, and the wrinkled green peas had the genotype rryy. All of the F1 offspring produced round yellow peas. These results showed that the alleles for yellow and round peas are dominant. As the Punnett square in Figure 11–9 shows, the genotype in each of these F1 plants is RrYy: In other words, the F1 plants were all heterozygous for both seed shape and seed color. This cross did not indicate whether genes assort, or segregate independently. However, it provided the hybrid plants needed to breed the F2 generation.

The Two-Factor Cross: F2

In the second part of this experiment, Mendel crossed the F1 plants to produce F2 offspring. Remember, each F1 plant was formed by the fusion of a gamete carrying the dominant RY alleles with another gamete carrying the recessive ry alleles. Did this mean that the two dominant alleles would always stay together, or would they segregate independently—so that any combination of alleles was possible?

In Mendel’s experiment, the F2 plants produced 556 seeds. Mendel compared their variation. He observed that 315 of the seeds were round and yellow, while another 32 seeds were wrinkled and green—the two parental phenotypes. However, 209 seeds had combinations of phenotypes, and therefore combinations of alleles, that were not found in either parent. This clearly meant that the alleles for seed shape segregated independently of those for seed color. Put another way, genes that segregate independently (such as the genes for seed shape and seed color in pea plants) do not influence each other’s inheritance.

Mendel’s experimental results were very close to the 9 : 3 : 3 : 1 ratio that the Punnett square shown in Figure 11–10 predicts. Mendel had discovered the principle of independent assortment. The principle of independent assortment states that genes for different traits can segregate independently during the formation of gametes. Independent assortment helps account for the many genetic variations observed in plants, animals, and other organisms—even when they have the same parents.

Quick Facts

**CALCULATING PROBABILITIES WITHOUT PUNNETT SQUARES**

You can obtain the outcomes of dihybrid or trihybrid crosses without setting up a Punnett square by multiplying probabilities. The ratio of dominant to recessive phenotypes in a monohybrid cross is 3:1. Using the example of seed color and shape, the chance of showing the dominant phenotype, having YY (or RR) or Yy (or Ry), in a monohybrid cross is 3/4. The chance of showing the recessive phenotype, having yy (or rr) is 1/4. You can find the chance of yellow, round peas by multiplying those two probabilities (3/4 × 3/4 = 9/16). If a third trait is added, for example, pod color, the same rules apply. Green pod color is dominant over yellow, so the chance of GG or Gg is 3/4 and the chance of gg is 1/4. For example, the probability of offspring with green, wrinkled peas and green pods is 3/64 (1/4 × 1/4 × 3/4).

**Use Visuals**

Tell students the two-factor cross they learned about in Figure 11–8 is called a “dihybrid cross” because it involves two different traits. Refer them to Figure 11–9, and discuss the results of the F1 cross.

**Ask** Why didn’t Mendel know, from the results of the first cross, whether two genes segregated independently? (All the offspring had dominant alleles.)

**Ask** What evidence did Mendel have that alleles segregated independently in the cross shown in Figure 11–10? (All combinations of phenotypes resulted.)

**Ask** What phenotypes would Mendel have observed if the alleles did not segregate independently—in other words, if the RY always stayed together and the ry always stayed together? (round, yellow seeds and wrinkled, green seeds)

**DIFFERENTIATED INSTRUCTION**

**Special Needs** Help students who are overwhelmed by the symbols in the figures to write out the crosses using words. Use ROUND and YELLOW for the dominant alleles and wrinkled and green for the recessive ones. Tell students when a capitalized (dominant) word appears with a lowercase (recessive) word, the capitalized word is the trait that shows. Explain that with the symbols, the same letter is used for one gene, such as Rr, instead of RrW, because two alleles code for the same gene.

**Answers**

**FIGURE 11–9** The offspring are heterozygous for each trait (RrYy).
LESSON 11.2

Assess and RemEDIATE

EVALUATE UNDERSTANDING

Assign students different pea traits from Figure 11–3. Instruct them to set up a Punnett square to show a cross between two pea plants that are heterozygous for the trait. They should give both the genotypic and phenotypic ratio of the offspring. Then, have them complete the 11.2 Assessment.

REMEDIATION SUGGESTION

L1 Struggling Students If your students have trouble with Question 4, show them how to calculate that 29% (31/106) of the plants have white flowers. Explain that this is close to the 25% you would expect from a heterozygous cross, similar to the 3:1 ratio in the tall to short plants in the F₂ generation in Figure 11–7.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. the likelihood that a particular event will occur

1b. Punnett squares are used to show all of the combinations of alleles that might result from a cross and the likelihood that each might occur.

2a. During gamete formation, pairs of alleles for a gene segregate, or separate, independently of each other.

2b. 50 percent; the Punnett square should show a cross between a homozygous short plant (tt) and a heterozygous tall plant (Tt).

3a. The patterns of inheritance he observed form the basis of modern genetics.

3b. Fruit flies are small, easy to keep in the laboratory, and produce large numbers of offspring in a short period of time.

4. Of the 106 plants, 31 had white flowers; this is 29%, or approximately one-fourth, of the plants.

A Summary of Mendel’s Principles

What did Mendel contribute to our understanding of genetics?

As you have seen, Mendel’s principles of segregation and independent assortment can be observed through one- and two-factor crosses.

Mendel’s principles of heredity, observed through patterns of inheritance, form the basis of modern genetics. These principles are as follows:

- The inheritance of biological characteristics is determined by individual units called genes, which are passed from parents to offspring.
- Where two or more forms (alleles) of the gene for a single trait exist, some alleles may be dominant and others may be recessive.
- In most sexually reproducing organisms, each adult has two copies of each gene—one from each parent. These genes segregate from each other when gametes are formed.
- Alleles for different genes usually segregate independently of each other. Mendel’s principles don’t apply only to plants. At the beginning of the 1900s, the American geneticist Thomas Hunt Morgan wanted to use a model organism of another kind to advance the study of genetics. He decided to work on a tiny insect that kept showing up, uninvited, in his laboratory. The insect was the common fruit fly, Drosophila melanogaster, shown in Figure 11–11. Drosophila can produce plenty of offspring—a single pair can produce hundreds of young. Before long, Morgan and other biologists had tested all of Mendel’s principles and learned that they applied to flies and other organisms as well. In fact, Mendel’s basic principles can be used to study the inheritance of human traits and to calculate the probability of certain traits appearing in the next generation. You will learn more about human genetics in Chapter 14.
Beyond Dominant and Recessive Alleles

**What are some exceptions to Mendel's principles?**

Despite the importance of Mendel's work, there are important exceptions to most of his principles. For example, not all genes show simple patterns of inheritance. In most organisms, genetics is more complicated, because the majority of genes have more than two alleles. Also, many important traits are controlled by more than one gene. Understanding these exceptions allows geneticists to predict the ways in which more complex traits are inherited.

**Incomplete Dominance** A cross between two four o'clock (Mirabilis jalapa) plants shows a common exception to Mendel's principles. Some alleles are neither dominant nor recessive. As shown in Figure 11–12, the F₁ generation produced by a cross between red-flowered (RR) and white-flowered (WW) Mirabilis plants consists of pink-colored flowers (RW). Which allele is dominant in this case? Neither one. Cases in which one allele is not completely dominant over another are called **incomplete dominance.** In incomplete dominance, the heterozygous phenotype lies somewhere between the two homozygous phenotypes.

**Codominance** A similar situation arises from **codominance,** in which the phenotypes produced by both alleles are clearly expressed. For example, in certain varieties of chicken, the allele for black feathers is codominant with the allele for white feathers. Heterozygous chickens have a color described as “ermine,” speckled with black and white feathers. Unlike the blending of red and white colors in heterozygous four o’clocks, black and white colors appear separately in chickens. Many human genes, including one for a protein that controls cholesterol levels in the blood, show codominance, too. People with the heterozygous form of this gene produce two different forms of the protein, each with a different effect on cholesterol levels.

**Key Questions**

- What are some exceptions to Mendel’s principles?
- Does the environment have a role in how genes determine traits?

**Vocabulary**

- incomplete dominance
- codominance
- multiple allele
- polygenic trait

**Taking Notes**

- **Outline** Make an outline using the green and blue headings. As you read, write bulleted notes below each heading to summarize its topic.

**THINK ABOUT IT**  
Mendel’s principles offer a tidy set of rules with which to predict various patterns of inheritance. Unfortunately, biology is not a tidy science. There are exceptions to every rule, and exceptions to the exceptions. What happens if one allele is not completely dominant over another? What if a gene has several alleles?

**INCOMPLETE DOMINANCE**

- **In Figure 11–12,** in four o’clock plants, the alleles for red and white flowers show incomplete dominance. Heterozygous (RW) plants have pink flowers—a mix of red and white coloring.

**CODOMINANCE**

- **Incomplete Dominance**
- **Codominance**
**Human Blood Types**

Red blood cells carry antigens, molecules that can trigger an immune reaction, on their surfaces. Human blood type A carries an A antigen, type B has a B antigen, type AB has both antigens, and type O carries neither antigen. The gene for these antigens has three alleles: A, B, and O.

For a transfusion to succeed, it must not introduce a new antigen into the body of the recipient. So, a person with type A blood may receive type O, but not vice versa.

Another gene controls a second type of antigen, known as Rh factor. Rh+ individuals carry this antigen, while Rh- ones don’t. This chart of the U.S. population shows the percentage of each blood type.

1. **Interpret Graphs** Which blood type makes up the greatest percentage of the U.S. population?
2. **Calculate** What percentage of the total U.S. population has a positive Rh factor? What percentage has a negative Rh factor?

**Multiple Alleles** So far, our examples have described genes for which there are only two alleles, such as a and A. In nature, such genes are the exception rather than the rule. **Many genes exist in several different forms and are therefore said to have multiple alleles.** A gene with more than two alleles is said to have multiple alleles. An individual, of course, usually has only two copies of each gene, but many different alleles are often found within a population. One of the best-known examples is coat color in rabbits. A rabbit’s coat color is determined by a single gene that has at least four different alleles. The four known alleles display a pattern of simple dominance that can be used for transfusion into the largest percentage of individuals. Which type has the smallest percentage of possible donors available?

**Polygenic Traits** Many traits are produced by the interaction of several genes. Traits controlled by two or more genes are said to be polygenic traits. Polygenic means “many genes.” For example, at least three genes are involved in making the reddish-brown pigment in the eyes of fruit flies. Polygenic traits often show a wide range of phenotypes. The variety of skin color in humans comes about partly because more than four different genes probably control this trait.

**Address Misconceptions**

**Polygenic Traits** Many students think that one gene is always responsible for one trait. Explain that such a case is actually rare. Most traits—such as hair and eye color in humans—are influenced by multiple genes.

**Answers**

**IN YOUR NOTEBOOK** Students’ descriptions should reflect that multiple alleles are more than two forms of the same gene in a population and polygenic traits have more than one gene contributing to the phenotype of an individual.

**ANswERS**

1. **O+**
2. **85% are Rh+; 15% are Rh−.**
3. **O− can be used for 100% of individuals; AB+ can be used for only 4%.**
4. **No, because both parents would be homozygous recessive for the Rh factor. They do not have any Rh+ alleles to pass on. This person could not have an AB+ daughter, because a person with O+ blood has only O alleles to pass on.**
Genes and the Environment

Does the environment have a role in how genes determine traits?

The characteristics of any organism—whether plant, fruit fly, or human being—are not determined solely by the genes that organism inherits. Genes provide a plan for development, but how that plan unfolds also depends on the environment. In other words, the phenotype of an organism is only partly determined by its genotype.

Consider the western white butterfly, *Pontia occidentalis*, shown in Figure 11–13. It is found throughout western North America. Butterfly enthusiasts had noted for years that western whites hatching in the summer (right) had different color patterns on their wings than those hatching in the spring (left). Scientific studies showed the reason—butterflies hatching in the shorter days of springtime had greater levels of pigment in their wings, making their markings appear darker than those hatching in the longer days of summer. In other words, the environment in which the butterflies develop influences the expression of their genes for wing coloration. Environmental conditions can affect gene expression and influence genetically determined traits. An individual’s actual phenotype is determined by its environment as well as its genes.

In the case of the western white butterfly, these changes in wing pigmentation are particularly important. In order to fly effectively, the body temperature of the butterfly must be 28ºC–40ºC (about 84ºF–104ºF). Since the spring months are cooler in the west, greater pigmentation helps them reach the body temperature needed for flight. Similarly, in the hot summer months, less pigmentation enables the moths to avoid overheating.

Assessment Answers

1a. In incomplete dominance, neither of the two alleles is dominant. The phenotype is a blend of the two alleles, such as pink flowers from red and white parents.

1b. Sample answer: Cross two petunia plants with pink flowers. If some of the offspring have red, some have white, and others have pink flowers, the pink color is caused by incomplete dominance.

2a. The environment affects how genes are expressed and therefore influence an organism’s phenotype.

2b. The higher temperatures of an unusually hot spring will likely result in lighter wing colors.

3. Students’ problems should follow the rules of genetics and include correct and complete answers.

Assess and Remediate

EVALUATE UNDERSTANDING
Ask volunteers to explain the four patterns of inheritance described in this lesson, as well as how environmental factors can influence phenotypes. Then, have students complete the 11.3 Assessment.

REMEDIATION SUGGESTION

• Advanced Students Challenge students to design an experiment that shows how environment affects phenotype, using cuttings from a coleus plant.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Answers

FIGURE 11–13 1.5ºC; No, because the average summer temperature is greater than the minimum temperature the butterflies need to fly.
If you enjoy learning about genetics, you may want to pursue one of the careers listed below.

**FORENSIC SCIENTIST**
Do you enjoy solving puzzles? That’s what forensic scientists do when they solve crimes. Local, state, and federal agencies employ forensic scientists to use scientific approaches that support criminal investigations. Criminalists are forensic scientists who specialize in the analysis of physical evidence, such as hair, fiber, DNA, fingerprints, and weapons. They are often called to testify in trials as expert witnesses.

**PLANT BREEDER**
Did you ever wonder how seedless watermelons become seedless? They are the product of a plant breeder. Plant breeders use genetic techniques to manipulate crops. Often, the goal is to make a crop more useful by increasing yield or nutritional value. Some breeders introduce new traits, such as pesticide resistance, to the plant’s genetic makeup.

**POPULATION GENETICIST**
Why are certain populations more susceptible to particular diseases? This is the kind of question that population geneticists answer. Their goal is to figure out why specific traits of distinct groups of organisms occur in varying frequencies. The patterns they uncover can lead to an understanding of how gene expression changes as a population evolves.

**CAREER CLOSE-UP:**
Sophia Cleland, Population Geneticist and Immunologist
Sophia Cleland, a Ph.D. student in immunology at George Washington University, studies the molecular, cellular, and genetic mechanisms that contribute to autoimmune diseases. One of only a few Native Americans with an advanced degree in genetics, Ms. Cleland became interested in autoimmune diseases when she noticed that the frequencies of these illnesses, such as rheumatoid arthritis and lupus, were several times higher among her tribal communities (Lakota-Sioux and California Mission Indian) than among Caucasians. Furthermore, she observed that such diseases progressed more rapidly among these communities than in any other human group in the world. Because of the frequency and severity of these diseases among indigenous tribal groups, Ms. Cleland is spreading the word about the need for focused research in this area.

“A compromise is needed between the world views of indigenous tribal groups and modern scientific approaches to gathering knowledge. We will encounter difficulties, but by working together with an open mind to learn, balanced and just results are possible.”

**Quick Facts**

**THE GENETICS OF LUPUS**
Lupus presents in different forms, but the most common type damages joints, skin, blood vessels, and organs such as the kidneys and brain. The disease has no cure. Lupus has a complex inheritance pattern. It runs in families but is not solely a genetic disease, leading scientists to think lupus has a genetic susceptibility and is polygenic. The genes involved in lupus vary in populations. The prevalence of lupus is higher in African Americans, Latinos, Asians, and Native Americans. Because lupus is rare in Africa, some scientists think environmental risk factors that are common in the United States and Europe but rare in Africa might trigger the disease.
**11.4 Meiosis**

**THINK ABOUT IT** As geneticists in the early 1900s applied Mendel’s principles, they wondered where genes might be located. They expected genes to be carried on structures inside the cell, but which structures? What cellular processes could account for segregation and independent assortment, as Mendel had described?

**Chromosome Number**

How many sets of genes are found in most adult organisms?

To hold true, Mendel’s principles require at least two events to occur. First, an organism with two parents must inherit a single copy of every gene from each parent. Second, when that organism produces gametes, those two sets of genes must be separated so that each gamete contains just one set of genes. As it turns out, chromosomes—those strands of DNA and protein inside the cell nucleus—are the carriers of genes. The genes are located in specific positions on chromosomes.

**Diploid Cells** Consider the fruit fly that Morgan used, *Drosophila*. A body cell in an adult fruit fly has eight chromosomes, as shown in Figure 11–14. Four of the chromosomes come from its male parent, and four come from its female parent. These two sets of chromosomes are homologous (hoh mah uh guhs), meaning that each of the four chromosomes from the male parent has a corresponding chromosome from the female parent. A cell that contains both sets of homologous chromosomes is said to be diploid, meaning “two sets.” The diploid cells of most adult organisms contain two complete sets of inherited chromosomes and two complete sets of genes. The diploid number of chromosomes is sometimes represented by the symbol 2N. Thus, for *Drosophila*, the diploid number is 8, which can be written as 2N = 8, where N represents the single set of chromosomes found in a sperm or egg cell.

**Haploid Cells** Some cells contain only a single set of chromosomes, and therefore a single set of genes. Such cells are haploid, meaning “one set.” The gametes of sexually reproducing organisms, including fruit flies and peas, are haploid. For *Drosophila* gametes, the haploid number is 4, which can be written as N = 4.

**Key Questions**
- How many sets of genes are found in most adult organisms?
- What events occur during each phase of meiosis?
- How is meiosis different from mitosis?
- How can two alleles from different genes be inherited together?

**Vocabulary**
- homologous
- diploid
- haploid
- meiosis
- tetrad
- crossing-over
- zygote

**Taking Notes**

*Compare/Contrast Table* Before you read, make a compare/contrast table to show the differences between mitosis and meiosis. As you read, complete the table.

**Figure 11–14 Fruit Fly Chromosomes** These chromosomes are from a fruit fly. Each of the fruit fly’s body cells is diploid, containing eight chromosomes.

**Objectives**

11.4.1 Contrast the number of chromosomes in body cells and in gametes.
11.4.2 Summarize the events of meiosis.
11.4.3 Contrast meiosis and mitosis.
11.4.4 Describe how alleles from different genes can be inherited together.

**Student Resources**

Study Workbook A and B, 11.4 Worksheets
Spanish Study Workbook, 11.4 Worksheets
Lab Manual B, 11.4 Data Analysis Worksheet

**Build Background**

Create a class Cluster Diagram for meiosis. Write the term on the board, and have student volunteers add any facts, terms, or concepts they know to the diagram. Refer to the cluster diagram as you work through the lesson.


**Teach for Understanding**

**Enduring Understanding** DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

**Guiding Question** How does a cell divide to create cells with exactly half of the original cell’s genetic information?

**Evidence of Understanding** After completing the lesson, give students the following assessment to show they understand how a cell divides to create cells with exactly half of the original cell’s genetic information. Have students use colored pencils to draw their own labeled diagrams of the phases of meiosis. In their diagrams, have them show how genes assort independently. Suggest they use homozygous alleles Y and y.
**Teach**

**Use Visuals**

Use Figure 11–15 to help students understand the process of meiosis I. Emphasize that before meiosis begins, every chromosome is copied, so the cell has four copies of each chromosome. Review the structures shown in the Prophase I cell and in the close-up of crossing-over. Have students identify those structures. Then, use the figure to walk students through meiosis I.

**DIFFERENTIATED INSTRUCTION**

- **Struggling Students** Some students might be confused by the number of chromosomes at each stage. Remind them that *haploid* and *diploid* refer to the number of sets of chromosomes in a cell. Help them understand that at the beginning of interphase, the cell is diploid or 2N. In this case, it contains two chromosomes. Emphasize that this is not shown in the figure. Explain that, during interphase, the chromosomes replicate and the cell becomes 4N (it has 8 chromatids, or 4 chromosomes). Have students verify that the cells are still 4N in the prophase, metaphase, and anaphase stages. When the cells divide in telophase I and cytokinesis, each cell has half the number of chromosomes, but it is not considered diploid because it contains only one duplicated set of chromosomes.

- **Focus on ELL:**
  **Build Background**

**BEGINNING AND INTERMEDIATE SPEAKERS**

Refer students to Figure 11–15, and have them identify the cell structures they learned about when they studied mitosis. Point out the centrioles, chromosomes, centromeres, and spindles. Use previously learned and new vocabulary terms frequently as you walk them through the visual and ask questions requiring them to use those terms. Then, have students draw and label their own diagrams of the phases of meiosis. Beginning speakers can use single words or phrases or their native language to write captions. Intermediate speakers should write complete sentences. Ask students to describe their diagrams to a partner.

**Answers**

**FIGURE 11–15** During crossing-over, the alleles can be exchanged between chromatids of homologous chromosomes to produce new combinations of alleles.

**Phases of Meiosis**

**What events occur during each phases of meiosis?**

How are haploid (N) gamete cells produced from diploid (2N) cells? That's where meiosis (my oh sis) comes in. **Meiosis** is a process in which the number of chromosomes per cell is cut in half through the separation of homologous chromosomes in a diploid cell. Meiosis usually involves two distinct divisions, called meiosis I and meiosis II. By the end of meiosis II, the diploid cell becomes four haploid cells. Let’s see how meiosis takes place in a cell that has a diploid number of 4 (2N = 4).

**Meiosis I** Just prior to meiosis I, the cell undergoes a round of chromosome replication during interphase. As in mitosis, which was discussed in Chapter 10, each replicated chromosome consists of two identical chromatids joined at the center. Follow the sequence in Figure 11–15 as you read about meiosis I.

- **Prophase I** After interphase I, the cell begins to divide, and the chromosomes pair up. **In prophase I of meiosis, each replicated chromosome pairs with its corresponding homologous chromosome.** This pairing forms a structure called a **tetrad**, which contains four chromatids. As the homologous chromosomes form tetrads, they undergo a process called **crossing-over**. First, the chromatids of the homologous chromosomes cross over one another. Then, the crossed sections of the chromatids—which contain alleles—are exchanged. Crossing-over therefore produces new combinations of alleles in the cell.

- **Metaphase I and Anaphase I** As prophase I ends, a spindle forms and attaches to each tetrad. **During metaphase I of meiosis, paired homologous chromosomes line up across the center of the cell.** As the cell moves into anaphase I, the homologous pairs of chromosomes separate. **During anaphase I, spindle fibers pull each homologous chromosome pair toward opposite ends of the cell.**

- **Telophase I and Cytokinesis** When anaphase I is complete, the separated chromosomes cluster at opposite ends of the cell. **The next phase is telophase I, in which a nuclear membrane forms around each cluster of chromosomes.** Cytokinesis follows telophase I, forming two new cells.

**Biology In-Depth**

**GENETIC VARIATION IN MEIOSIS PHASES**

Genetic variation occurs during meiosis in several phases. During prophase I crossing-over, sister chromatids become attached and swap sections at points called chiasmata. The sections are portions of adjacent DNA molecules. Neither chromatid gains or loses any genes. In humans (23 chromosomes), if only one cross-over event occurs in each tetrad (and it is usually two or three), over 70 trillion combinations are possible \(4^{23}\). During metaphase I, homologous pairs of chromosomes line up randomly with respect to orientation; each pair can line up in two different ways. The number of possible combinations is over 8 million \(2^{23}\). When those numbers are multiplied together and that result is multiplied by two because of fertilization, you can see why each person is unique!
Meiosis I results in two cells, called daughter cells. However, because each pair of homologous chromosomes was separated, neither daughter cell has the two complete sets of chromosomes that it would have in a diploid cell. Those two sets have been shuffled and sorted almost like a deck of cards. The two cells produced by meiosis I have sets of chromosomes and alleles that are different from each other and from the diploid cell that entered meiosis I.

**Meiosis II** The two cells now enter a second meiotic division. Unlike the first division, neither cell goes through a round of chromosome replication before entering meiosis II.

**Prophase II** As the cells enter prophase II, their chromosomes—each consisting of two chromatids—become visible. The chromosomes do not pair to form tetrads, because the homologous pairs were already separated during meiosis I.

**Metaphase II, Anaphase II, Telophase II, and Cytokinesis** During metaphase of meiosis II, chromosomes line up in the center of each cell. As the cell enters anaphase, the paired chromatids separate. The final four phases of meiosis II are similar to those in meiosis I. However, the result is four haploid daughter cells. In the example shown here, each of the four daughter cells produced in meiosis II receive two chromosomes. These four daughter cells now contain the haploid number (N)—just two chromosomes each.

**Gametes to Zygotes** The haploid cells produced by meiosis II are the gametes that are so important to heredity. In male animals, these gametes are called sperm. In some plants, pollen grains contain haploid sperm cells. In female animals, generally only one of the cells produced by meiosis is involved in reproduction. The female gamete is called an egg in animals and an egg cell in some plants. After it is fertilized, the egg is called a zygote (zy goht). The zygote undergoes cell division by mitosis and eventually forms a new organism.

**In Your Notebook** Describe the difference between meiosis I and meiosis II. How are the end results different?

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**Check for Understanding**

**USE VOCABULARY**

Ask students to create a jingle, acronym, or other mnemonic to help them remember what happens in each phase of meiosis I and II. Suggest they use the vocabulary terms whenever possible. An example is a cheer: (for meiosis I) “Give me a P—paired chromosomes form a tetrad, give me an M—meet in the middle and line up, give me an A—away from the middle, give me a TC—two cells.”

**ADJUST INSTRUCTION**

If students have difficulty creating the mnemonic or it is incorrect, have them reread the boldface statements under Phases of Meiosis. Tell them to focus on the movements of the chromosomes or what is happening to them. For example, for prophase II, have them focus on “become visible.” Then, tell them to think of a memory device for that action. For a cheer, an example is “Give me a P—pops up.”

**Use Visuals**

Draw students’ attention to the two cells at the top of Figure 11–16. Reinforce that, while each has a 2N number of chromosomes, the cells are not considered diploid because the chromatid strands in the replicated chromosomes came from the same parent. Then, have volunteers use their own words to describe what occurs during each step of meiosis II.

**Ask** How many haploid (N) daughter cells are produced at the end of meiosis II? (four)

**Ask** What are some differences between meiosis I and meiosis II? (Sample answer: homologous chromosomes separate during meiosis I but not during meiosis II. The centromeres and sister chromatids separate during meiosis II.)

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**DIFFERENTIATED INSTRUCTION**

**Special Needs** Help students model the steps in meiosis using pipe cleaners of the same color to represent chromosome pairs, with different pairs having different colors. Monitor students to make sure they double each chromosome before meiosis begins by adding another pipe cleaner of the same color. They can use beads to hold the chromatids together or twist the pipe cleaners together in the middle. Make sure they separate the chromosome pairs during meiosis I and the chromatids during meiosis II.

**Less Proficient Readers** Have students write an outline of meiosis in which each major step is a main heading. Suggest they include the information in the boldface Key Concepts as details.

Students can view the phases of meiosis online in Art in Motion: Meiosis. For extra help, have students view Tutor Tube: Connecting Punnett Squares to Meiosis.

**Answers**

**IN YOUR NOTEBOOK** Answers should include the following: Meiosis I involves chromosome replication, formation of tetrads, crossing-over, separation of paired homologous chromosomes, and division into two cells. Meiosis II includes separation of sister chromatids as each cell divides. The end result of meiosis I is two genetically different cells, each containing the same number of chromosomes as the original cell but recombined due to crossing-over. The end result of meiosis II is four different haploid cells.
Have students compare and contrast mitosis and meiosis using Figure 11–17. Draw particular attention to phases in meiosis where genetic recombination occurs. For example, in prophase in mitosis, the replicated chromosomes do not pair up, whereas in prophase I in meiosis, the replicated chromosomes pair up with their homologues and the process of crossing-over occurs.

As you walk students through the Visual Summary, have them note differences in the lining up of chromosomes, the number of chromosomes each cell contains, and how chromosomes separate into new cells.

DIFFERENTIATED INSTRUCTION

**L1 Special Needs** Provide students with beads and pipe cleaners of different colors, and have them model the steps in mitosis. Help them to arrange this model next to the model they made of meiosis earlier. Then, ask them to explain what is happening in each phase of mitosis and tell how those phases are similar and different to those of meiosis. Suggest students glue their models to poster board to use as a study guide.

**L1 Struggling Students** Students who have difficulty understanding the Visual Summary might benefit from drawing diagrams that show only the chromosomes without the distraction of other structures, such as the spindle fibers. Help them draw circles for each phase of mitosis and meiosis and fill in only the chromosomes at each stage. Then, have them write simple captions that describe what is happening in each phase.

**L3 Advanced Students** To add detail to the students’ comparisons of mitosis and meiosis, have them create a third column for Figure 11–17 on a separate sheet of paper labeled Meiosis II. Have students use Figure 11–16 as a model for drawing corresponding diagrams for prophase II, metaphase II, anaphase II, and telophase II. Then, have students use their extended visual summary to compare the two processes in more detail.

**Biology In-Depth**

**POLAR BODIES**

In many female animals, cytokinesis at the end of meiosis I and meiosis II is uneven. At the end of meiosis I, one of the cells receives most of the cytoplasm and is called a secondary oocyte. The cell that receives very little is the polar body. At the end of meiosis II, the secondary oocyte divides so that once again one cell receives most of the cytoplasm; this cell becomes the egg, and the other cell is another polar body. The polar body formed at the end of meiosis I divides into two polar bodies in meiosis II. The three polar bodies eventually die. The reason for the uneven divisions is the allotment of more materials in the egg cell to nourish the zygote.
Calculating Haploid and Diploid Numbers

Haploid and diploid numbers are designated by the algebraic notations N and 2N, respectively. Either number can be calculated when the other is known. For example, if the haploid number (N) is 3, the diploid number (2N) is 2 × 3, or 6. If the diploid number (2N) is 12, the haploid number (N) is 12/2, or 6.

The table shows haploid or diploid numbers of a variety of organisms. Copy the table into your notebook and complete it. Then, use the table to answer the questions that follow.

<table>
<thead>
<tr>
<th>Organism</th>
<th>Haploid Number</th>
<th>Diploid Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amoeba</td>
<td>N=25</td>
<td></td>
</tr>
<tr>
<td>Chimpanzee</td>
<td>N=24</td>
<td></td>
</tr>
<tr>
<td>Earthworm</td>
<td>N=18</td>
<td></td>
</tr>
<tr>
<td>Fern</td>
<td></td>
<td>2N=1010</td>
</tr>
<tr>
<td>Hamster</td>
<td>N=22</td>
<td></td>
</tr>
<tr>
<td>Human</td>
<td></td>
<td>2N=46</td>
</tr>
<tr>
<td>Onion</td>
<td></td>
<td>2N=16</td>
</tr>
</tbody>
</table>

1. **Calculate** What are the haploid numbers for the fern and onion plants?
2. **Interpret Data** In the table, which organisms’ diploid numbers are closest to that of a human?
3. **Apply Concepts** Why is a diploid number always even?
4. **Evaluate** Which organism’s haploid and diploid numbers do you find the most surprising? Why?
LESSON 11.4

Teach continued

Use Models

Have students demonstrate why genes that are close together do not usually assort independently. Ask them to use two differently colored markers to draw two paired chromosomes. Have them place three symbols (in the same color as the chromosome) along each chromosome to indicate the relative positions of the genes for star eye, dumpy wing, and speck wing as indicated in Figure 11–18. Then, have another student point to the same spot on both chromosomes to identify a location for crossing-over. Have pairs redraw the chromosomes as if crossing-over occurred, using the two colors to show the parts of the chromosomes that have exchanged. Then, have them use the symbols to check for gene linkage.

Ask Which genes are most likely inherited together? Why? (Star eye and dumpy wing. Because these genes are so close together on the chromosome, the chance that crossing-over would separate them is smaller.)

DIFFERENTIATED INSTRUCTION

ELL Struggling Students Refer students who need extra help to the close-up image of crossing-over in Figure 11–15. Point out that chunks of the chromosomes, not individual genes, are exchanged between chromosomes. Have students model gene linkage in crossing-over by using different colors of modeling clay to represent each chromosome. Students can pull apart chunks of one color clay and attach them to the other color.

ELL English Language Learners Show students a road map, and point out how maps show where things such as cities and roads are located. Then, point to Figure 11–18, and tell them a gene map shows where genes are located.

Students can analyze the connection between crossing-over and gene location in Data Analysis: Gene Location and Crossing-Over.

Answers

FIGURE 11–18 The “purple eye” gene is located at 54.5.

Check for Understanding

FOLLOW-UP PROBES

Ask students the following questions:

• Why are the alleles for reddish-orange eyes and miniature wings in fruit flies usually inherited together? (The genes are located near each other on the same chromosome.)

• Morgan found that fruit flies, with their four pairs of chromosomes, had four linkage groups. Why does this make sense? (Each chromosome is a set of linked genes.)

ADJUST INSTRUCTION

If students have difficulty answering the questions, have them reread the text on gene linkage and Morgan’s work. Have pairs of students summarize Morgan’s work. Ask several pairs to share their summaries with the class.
Morgan’s findings led to two remarkable conclusions. First, each chromosome is actually a group of linked genes. Second, Mendel’s principle of independent assortment still holds true. It is the chromosomes, however, that assort independently, not individual genes.

Alleles of different genes tend to be inherited together from one generation to the next when those genes are located on the same chromosome.

How did Mendel manage to miss gene linkage? By luck, or design, several of the genes he studied are on different chromosomes. Others were on the same chromosome.

Sturtevant gathered up several notebooks of lab data and took them back to his room. The next morning, he presented Morgan with a gene map showing the relative locations of each known gene on one of the Drosophila chromosomes. Sturtevant’s method has been used to construct gene maps, like the one in Figure 11–18, ever since this discovery.

**Assess and Remediate**

**EVALUATE UNDERSTANDING**

Have students verbally list the stages of meiosis in order and describe in their own words what occurs during each stage. Then, have them complete the 11.4 Assessment.

**REMEDIATION SUGGESTION**

- **Struggling Students** If your students have trouble with Question 3, review with them the text of Diploid Cells and the first paragraph of Meiosis I. Then, have them draw diagrams to show how homologous chromosomes are formed from two parent cells joining and how sister chromatids are formed by replication within a single cell.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

**Assessment Answers**

1a. Meiosis results in four haploid cells that are genetically different from one another and from the original cell.

1b. Each gamete cell has 23 chromosomes.

2a. Check that student answers include accurate summaries of interphase I, prophase I and II, metaphase I and II, anaphase I and II, telophase I and II, and cytokinesis I and II.

2b. Shoes are in pairs as are chromosomes in a diploid cell. A “haploid” shoe collection would have only one shoe of each kind.

3a. Mitosis produces two genetically identical diploid cells. Meiosis produces four genetically different haploid cells.

3b. The sister chromatids are identical, because one is a copy of the other. The homologous pairs are not identical; one chromosome comes from the mother and one comes from the father.

4a. It is the chromosomes that assort independently, not individual genes.

4b. The two genes are located very far apart from each other.

5. Sexual reproduction; during meiosis, the shuffling and separating of homologous chromosomes and crossing-over events produce gametes genetically different from each other and from the original cell. Fertilization with a gamete from a different parent further increases genetic variation.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Modeling Meiosis described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 280.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP II
CONTENT C.1.a
INQUIRY A.1.d

Pre-Lab: Modeling Meiosis

Problem How does meiosis increase genetic variation?

Materials pop-it beads, magnetic centromeres, large sheet of paper, colored pencils, scissors

Lab Manual Chapter 11 Lab

Skills Use Models, Sequence, Draw Conclusions

Connect to the Big idea Inherited traits are passed from parents to offspring in the form of genes. Offspring produced by sexual reproduction receive one set of genes from each parent when the reproductive cells, or gametes, combine. Meiosis is the process by which gametes are produced. During meiosis, new combinations of genes form when genes cross over from one homologous chromosome to the other. Also, the sorting of chromatids among gametes is random. Both crossing-over and sorting lead to greater diversity in the genes of a population.

In this lab, you will model the steps of meiosis and track what happens to alleles as they move from diploid cells to haploid gametes.

Background Questions

a. Review What are alleles?
b. Sequence What happens during prophase I of meiosis? What happens during metaphase I? What happens during anaphase I?
c. Compare and Contrast In what ways does meiosis differ from mitosis?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. Control Variables Why must you use the same number of beads when you construct the second chromosome in Step 1?
2. Infer Why is the longer chromosome pair used to model crossing-over?
3. Calculate A diploid cell has two pairs of homologous chromosomes. How many different combinations of chromosomes could there be in the gametes?

Pre-Lab Answers

BACKGROUND QUESTIONS

a. Alleles are different forms of the same gene.
b. During prophase I, homologous chromosomes form tetrads. The tetrads line up across the center of the cell during metaphase I and are pulled to opposite ends of the cells during anaphase I.
c. During meiosis, homologous chromosomes separate, two cell divisions occur, and daughter cells have half as many chromosomes. During mitosis, homologous chromosomes are not separated, only one cell division occurs, and the number of chromosomes per cell does not change.

PRE-LAB QUESTIONS

1. There must be an allele for each gene on each chromosome in the homologous pair.
2. Genes that are on the same chromosome are likely to be linked. The chances of crossing-over are greater on the longer chromosome.
3. There could be four different combinations (ignoring any variation due to crossing-over).
11 Study Guide

Big Idea Information and Heredity

Genetic information passes from parent to offspring during meiosis when gametes, each containing one representative from each chromosome pair, unite.

11.1 The Work of Gregor Mendel

An individual’s characteristics are determined by factors that are passed from one parental generation to the next.

During gamete formation, the alleles for each gene segregate from each other so that each gamete carries only one allele for each gene.

11.2 Applying Mendel’s Principles

Punnett squares use mathematical probability to help predict the genotype and phenotype combinations in genetic crosses.

The principle of independent assortment states that genes for different traits can segregate independently during the formation of gametes.

Mendel’s principles of heredity, observed through patterns of inheritance, form the basis of modern genetics.

11.3 Other Patterns of Inheritance

Some alleles are neither dominant nor recessive. Many genes exist in several different forms and are therefore said to have multiple alleles. Many traits are produced by the interaction of several genes.

Environmental conditions can affect gene expression and influence genetically determined traits.

incomplete dominance (319) multiple allele (320)
codominance (319) polygenic trait (320)

11.4 Meiosis

The diploid cells of most adult organisms contain two complete sets of inherited chromosomes and two complete sets of genes.

In prophase I, replicated chromosomes pair with corresponding homologous chromosomes. At metaphase I, paired chromosomes line up across the center of the cell. In anaphase I, chromosome pairs move toward opposite ends of the cell. In telophase I, a nuclear membrane forms around each cluster of chromosomes. Cytokinesis then forms two new cells. As the cells enter prophase II, their chromosomes become visible. The final four phases of meiosis II result in four haploid daughter cells.

In mitosis, when the two sets of genetic material separate, each daughter cell receives one complete set of chromosomes. In meiosis, homologous chromosomes line up and then move to separate daughter cells. Mitosis does not normally change the chromosome number of the original cell. Meiosis reduces the chromosome number by half. Mitosis results in the production of two genetically identical diploid cells, whereas meiosis produces four genetically different haploid cells.

Alleles of different genes tend to be inherited together from one generation to the next when those genes are located on the same chromosome.

11.5 Standardized Test Prep

Students can take an online version of the Standardized Test Prep. You will receive their scores along with ideas for remediation.

Performance Tasks

SUMMATIVE TASK Have students write a story about a chromosome going through meiosis for the first time. Encourage them to use illustrations and to be creative, but they must give accurate information about the movement of chromosomes.

TRANSFER TASK Tell students to imagine they are dog breeders for a particular breed. Spotted coats are dominant over solid coats, and curly coats are dominant over straight coats. They mate two dogs with spotted, curly coats. Two puppies have spotted, curly coats, and two have solid, straight coats. Another breeder claims the phenotypes must be due to gene linkage and cannot be due to a two-factor cross in which the two genes are not linked. Have students explain how either explanation is plausible and draw diagrams to demonstrate their reasoning. Then, have them explain why it is important to a dog breeder to know whether the phenotypes are from a gene linkage or a dihybrid cross.

Answers

THINK VISUALLY

Students’ concept maps should include that a gene has two alleles, genes are located on chromosomes, genes help determine traits, and alleles can be dominant or recessive.
Lesson 11.1

UNDERSTAND KEY CONCEPTS
1. c 2. c
3. True-breeding organisms self-fertilize to produce offspring like themselves.
4. Mendel removed the pollen-producing parts from the flowers of his pea plants so they would not self-pollinate.

THINK CRITICALLY
5. Cross the white ram with a number of black ewes. If any offspring are black, then the white ram is heterozygous.
6. The original genotypes and the crosses could have been $Tt \times tt$ or $Tt \times Tt$. The genotype $TT$ could not have been present; if it were, all the offspring would be tall.

Lesson 11.2

UNDERSTAND KEY CONCEPTS
7. a 8. c 9. c
10. (1) The inheritance of biological characteristics is determined by genes. (2) Where there are two or more forms (alleles) of the gene for a single trait, some forms of the gene may be dominant and others recessive. (3) In most sexually reproducing organisms, each adult has two copies of each gene, one from each parent. These genes are segregated when gametes form. (4) The alleles for different genes (actually, the chromosomes) usually segregate independently.
11. $1 YY : 2 Yy : 1 yy$; the Punnett square should show a cross between two heterozygous plants ($Yy$).

THINK CRITICALLY
12. The result of each fertilization is independent of any previous fertilizations, so it is possible for all offspring to have smooth coats. Each offspring could receive a recessive allele from both its parents.

Lesson 11.3

UNDERSTAND KEY CONCEPTS
13. d 14. a
15. A single gene has multiple alleles if it has more than two alleles. Two or more genes control polygenic traits.
16. Many different phenotypes are possible, because, while individuals only have two alleles each, there can be many different alleles present in the population. Different possible allele combinations can yield different phenotypes.

17. No, genes provide a plan for development, but how the plan unfolds depends on the environment.

THINK CRITICALLY
18. The color helps the ptarmigan hide from predators. In winter, its white coat color blends in with its snowy surroundings.
Lesson 11.4

THINK CRITICALLY

25. Sample answer: Meiosis I results in two daughter cells with 2N chromosomes each, while meiosis II results in four daughter cells with N chromosomes each. In Prophase I, replicated, homologous chromosomes pair up to form tetrads, while in Prophase II, the chromosomes do not replicate or form tetrads. In Metaphase I, homologous pairs of chromosomes separate, while in Metaphase II, paired chromatids separate. The final four phases of meiosis I and meiosis II are similar.
Connecting Concepts

USE SCIENCE GRAPHICS
26. 66 smooth and 66 wrinkled
27. Yes, the observed numbers are close to the expected values. No other cross would predict a ratio close to 50 percent for each trait.
28. No, a similar outcome would result from a cross like this if wrinkled seeds were dominant.

WRITE ABOUT SCIENCE
29. Students’ explanations should be clear and concise and include examples. They should explain that a gene has at least two alleles. Some alleles are dominant and others are recessive. An organism with a dominant allele will always exhibit that form of the trait. Recessive alleles are expressed only in the absence of dominant alleles.
30. Students’ explanations should include that these two traits are located close together on the same chromosome. When alleles of different genes are close to each other, they are said to be linked. These genes tend to be inherited together. Diagrams should indicate the alleles’ positions on one chromosome as being close together throughout meiosis.
31. Pairs of genes are found on pairs of chromosomes. The pairs of chromosomes and their genes separate during meiosis and gamete formation. Each gamete gets only one of each pair of chromosomes and one of each pair of genes. In fertilization, chromosome pairs and their genes come together from each parent to form new combinations.

Use Science Graphics
Seed coat was one trait that Mendel studied in pea plants. The coat, or covering, of the seed is either smooth or wrinkled. Suppose a researcher has two plants—one that makes smooth seeds and another that makes wrinkled seeds. The researcher crosses the wrinkled-seed plants and the smooth-seed plants, obtaining the following data. Use the data to answer questions 26–28.

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth seeds</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Wrinkled seeds</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

26. Predict Mendel knew that the allele for smooth (R) seeds was dominant over the allele for wrinkled (r) seeds. If this cross was Rr × rr, what numbers would fill the middle column?
27. Analyze Data Are the observed numbers consistent with the hypothesis that the cross is Rr × rr? Explain your answer.
28. Draw Conclusions Are the data from this experiment alone sufficient to conclude that the allele for smooth seeds is dominant over the allele for wrinkled seeds? Why or why not?

A researcher studying fruit flies finds a mutant fly with brown-colored eyes. Almost all fruit flies in nature have bright red eyes. When the researcher crosses the mutant fly with a normal red-eyed fly, all of the F1 offspring have red eyes. The researcher then crosses two of the F1 red-eyed flies and obtains the following results in the F2 generation.

<table>
<thead>
<tr>
<th>Eye Color in the F2 Generation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Red eyes</td>
<td>37</td>
</tr>
<tr>
<td>Brown eyes</td>
<td>14</td>
</tr>
</tbody>
</table>

32. Calculate What is the ratio of red-eyed flies to brown-eyed flies? c. 3 : 1
   a. 1 : 1
   b. 1 : 3
   d. 4 : 1
33. Draw Conclusions The allele for red eyes in fruit flies is
   a. dominant over brown eyes.
   b. recessive to brown eyes.
   c. codominant with the brown-eyed gene.
   d. a multiple allele with the brown-eyed gene and others.
**Standardized Test Prep**

**Multiple Choice**

1. What happens to the chromosome number during meiosis?
   A It doubles.
   B It stays the same.
   C It halves.
   D It becomes diploid.

2. Which ratio did Mendel find in his $F_2$ generation?
   A 3 : 1
   B 1 : 3 : 1
   C 1 : 2
   D 3 : 4

3. During which phase of meiosis is the chromosome number reduced?
   A anaphase I
   B metaphase I
   C telophase I
   D telophase II

4. Two pink-flowering plants are crossed. The offspring flower as follows: 25% red, 25% white, and 50% pink. What pattern of inheritance does flower color in these flowers follow?
   A dominance
   B multiple alleles
   C incomplete dominance
   D polygenic traits

5. Which of the following is used to construct a gene map?
   A chromosome number
   B mutation rate
   C rate of meiosis
   D recombination rate

6. Alleles for the same trait are separated from each other during the process of
   A cytokinesis.
   B meiosis I.
   C meiosis II.
   D metaphase II.

7. Which of the following is NOT one of Gregor Mendel’s principles?
   A The alleles for different genes usually segregate independently.
   B Some forms of a gene may be dominant.
   C The inheritance of characteristics is determined by factors (genes).
   D Crossing-over occurs during meiosis.

**Questions 8–9**

Genes A, B, C, and D are located on the same chromosome. After calculating recombination frequencies, a student determines that these genes are separated by the following map units: C–D, 25 map units; A–B, 12 map units; B–D, 20 map units; A–C, 17 map units.

8. How many map units apart are genes A and D?
   A 5
   B 8
   C 10
   D 12.5

9. Which gene map best reflects the student’s data?
   A [Diagram with 5, B, 12, C, 8, D]
   B [Diagram with 8, B, 20, C, 6, D]
   C [Diagram with 8, B, 17, C, 12, D]
   D [Diagram with 5, B, 12, A, 8, D]

**Open-Ended Response**

10. Explain why meiosis allows organisms to maintain their chromosome numbers from one generation to the next.

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**Introduction to Genetics 335**

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**Test-Taking Tip**

**ANTICIPATE THE ANSWER**

Tell students to read the question stem and try to anticipate what the answer will be. Then, have them read all the answer choices carefully to see which choice best matches the answer they anticipated. Reinforce that they should read all the answer choices before selecting one.
Connect to the Big Idea

Ask students to describe the sculpture shown on this page. (Sample answer: circular, twisted, colorful) Point out the caption, which explains that this sculpture models the structure of DNA, a molecule that carries genetic information in living things.

Explain that the structure of DNA was not determined until the 1950s. Tell students that an understanding of DNA’s function gave some clues to its structure. Observations and experiments by many scientists also provided clues to DNA’s structure. Suggest students note the relationship between DNA’s structure and function as they read the chapter. Ask them to anticipate the answer to the question, What is the structure of DNA, and how does it function in genetic inheritance?

Have students read the Chapter Mystery. Ask them to make predictions about the relationship between UV light, cell damage, and skin cancer. After students have completed the chapter, have them compare their predictions to the information in the Chapter Mystery clues found throughout the chapter and online.

Have students preview the chapter vocabulary terms using the Flash Cards.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES
I, II, V

CONTENT
C.1.c, C.2.a, C.2.c, G.1, G.2, G.3

INQUIRY
A.1.b, A.1.c, A.1.d, A.2.a, A.2.b, A.2.c, A.2.d, A.2.e, A.2.f

Understanding by Design

In Chapter 12, students learn about experiments that helped reveal the structure and function of DNA as well as how DNA replicates. Use the ideas and questions shown in the graphic organizer at the right to connect Chapter 12 content with the Unit 4 Enduring Understanding: DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

PERFORMANCE GOALS

Students’ mastery of Chapter 12 content will be demonstrated by their responses to discussion questions found in this Teacher’s Edition and their completion of labs and data analysis activities. Additionally, the Performance Tasks require students to synthesize with chapter content by creating a chapter review software presentation and writing a letter from the point of view of Watson or Crick.
UV LIGHT

“Put on your sunscreen!” This familiar phrase can be heard at most beaches on a sunny day. It’s an important directive, though, because sunlight—for all its beneficial effects—can readily damage the skin. The most dangerous wavelengths of sunlight are the ones we can’t see: the ultraviolet (UV) region of the electromagnetic spectrum. Not only can excess exposure to UV light damage skin cells, it can cause a deadly form of skin cancer that kills nearly 10,000 Americans each year.

Why is UV light so dangerous? How can these particular wavelengths of light damage our cells to the point of causing cell death and cancer? As you read this chapter, look for clues to help you solve the question of why UV light is so damaging to skin cells. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the connection between UV light and DNA is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

INSIDE:
- 12.1 Identifying the Substance of Genes
- 12.2 The Structure of DNA
- 12.3 DNA Replication

What’s Online

Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
Students collect information about how UV light changes DNA and how DNA damage causes skin cancer to help them solve the mystery.

UNTAMED SCIENCE VIDEO
Follow the Untamed Science crew as they unlock the hidden information that can be found in DNA evidence from a crime scene.

ART IN MOTION
Students can watch an animated version of the experiment that convinced scientists DNA was the genetic material found in cells.

VISUAL ANALOGY
With this activity, students will watch the ways in which DNA can be compared to a “How-To” book.

DATA ANALYSIS
Students can analyze DNA data to assess the relatedness of different species.

TUTOR TUBE
This online tutorial offers some handy strategies for remembering which DNA bases pair together.

INTERACTIVE ART
Students can watch an animation of DNA replication and then drag-and-drop labels to test their understanding.

DATA ANALYSIS
Students analyze DNA sequences for the purpose of identifying illegally caught whales.

ART REVIEW
This drag-and-drop labeling activity helps students review the differences between prokaryotic and eukaryotic DNA replication.

Chapter 12
Big Idea:
Information and Heredity, Cellular Basis of Life

Chapter 12 EQ:
- What is the structure of DNA, and how does it function in genetic inheritance?
- How did scientists determine that DNA is responsible for storing, copying, and transmitting genetic information?
- How was the basic structure of DNA discovered?
- How do cells copy their DNA?
Getting Started

Objectives

12.1.1 Summarize the process of bacterial transformation.
12.1.2 Describe the role of bacteriophages in identifying genetic material.
12.1.3 Identify the role of DNA in heredity.

Student Resources

Study Workbooks A and B, 12.1 Worksheets
Spanish Study Workbook, 12.1 Worksheets

ACTIVATE PRIOR KNOWLEDGE

Have several volunteers describe how the information they learned in elementary and middle school prepared them for the academic work they are now doing in high school. Explain that scientific knowledge grows in a similar way. Tell students this lesson will describe experiments that laid the groundwork for current work in the scientific field of genetics.

Identifying the Substance of Genes

THINK ABOUT IT

How do genes work? To answer that question, the first thing you need to know is what genes are made of. After all, you couldn’t understand how an automobile engine works without understanding what the engine is made of and how it’s put together. So, how would you go about figuring out what molecule or molecules go into making a gene?

Bacterial Transformation

What clues did bacterial transformation yield about the gene?

Vocabulary

transformation bacteriophage

Taking Notes

Flowchart As you read this section, make a flowchart that shows how scientists came to understand the molecule known as DNA.

THINK ABOUT IT

What role did bacterial viruses play in identifying genetic material?

What is the role of DNA in heredity?

What clues did bacterial transformation yield about the gene?

Key Questions

Enduring Understanding

DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

Guiding Question

How did scientists determine that DNA is responsible for storing, copying, and transmitting genetic information?

Evidence of Understanding

After completing the lesson, give students the following assessment to show they understand how scientists identified the genetic material in cells. Have students work in small groups to write a newspaper article describing the work of either Frederick Griffith, Oswald Avery, or Alfred Hershey and Martha Chase. Explain that newspaper articles usually provide answers to the following set of questions: Who? What? Where? When? and Why? Have each group share its completed newspaper article with the class.
In Griffith's next experiment, he mixed the heat-killed, S-strain bacteria with live, harmless bacteria from the R strain. This mixture he injected into laboratory mice. By themselves, neither type of bacteria should have made the mice sick. To Griffith's surprise, however, the injected mice developed pneumonia, and many died. When he examined the lungs of these mice, he found them to be filled not with the harmless bacteria, but with the disease-causing bacteria. How could that happen if the S-strain cells were dead?

**Transformation**  Somehow, the heat-killed bacteria passed their disease-causing ability to the harmless bacteria. Griffith reasoned that, when he mixed the two types of bacteria together, some chemical factor transferred from the heat-killed cells of the S strain into the live cells of the R strain. This chemical compound, he hypothesized, must contain information that could change harmless bacteria into disease-causing ones. He called this process transformation, because one type of bacteria (the harmless form) had been changed permanently into another (the disease-causing form). Because the ability to cause disease was inherited by the offspring of the transformed bacteria, Griffith concluded that the transforming factor had to be a gene.

**In Your Notebook**  Write a summary of Griffith's experiments.

**Teach**

**Use Visuals**

Tell students the word transformation means “change.”

**Ask**  Why is the word transformation a good description of what happened in Griffith's experiment?  (Sample answer: One strain of bacteria transformed, or changed, into another.)

**Ask**  Why did Griffith conclude that the transforming factor had to be a gene?  (The factor was inherited by offspring of the transformed bacteria.)

**DIFFERENTIATED INSTRUCTION**

**ELL Less Proficient Readers**  Have struggling readers use Figure 12–1 to learn about Griffith's experiment. Point out and describe what happens in each vertical panel of the figure.

**Ask**  In this experiment, which strain of bacteria caused disease? (the S strain)

**Ask**  What happened when heat-killed S strain was injected into a mouse? (It no longer caused disease.)

**Ask**  What happened when the heat-killed S strain was mixed with the harmless R-strain bacteria? (The mouse got sick.)

**Focus on ELL: Extend Language**

**INTERMEDIATE SPEAKERS**  To understand the content of this lesson, students need a working knowledge of terms such as experiment, inferred, concluded, and observed. As students read about the experiments in this lesson, have them locate these terms in the text. Ask students to find a definition for each term in a dictionary and to practice pronouncing each term aloud.

**Answers**

**FIGURE 12–1**  to determine whether the substance transferred from the heat-killed bacteria to the R strain was heritable

**IN YOUR NOTEBOOK**  Students' summaries should include a description of the four different samples of bacteria Griffith injected into the mice, the fate of the mice injected with each strain, and the conclusion Griffith drew based on his results.
Teach continued

Lead a Discussion

Review with students the experimental design used by Avery and his team. Have students identify the manipulated, or independent, variable in the experiment. (the type of enzyme used to treat the extract from heat-killed bacteria) Make sure they realize that only one enzyme was used in each experiment. Then, have them identify the responding, or dependent, variable in this experiment. (whether transformation occurred) Have students state the conclusion that was reached using the results of these experiments. (DNA stores and transmits genetic information.)

DIFFERENTIATED INSTRUCTION

Struggling Students Provide students with a visual representation of Avery’s experiment. Start by drawing a cluster of heat-killed bacteria on the board. Then, draw an arrow from the bacteria to a test tube with liquid in it, while explaining that Avery extracted cellular materials from the bacteria. Draw protein-destroying enzymes being added to this test tube. Then, draw another arrow to a cluster of live R-strain bacteria, and tell students that Avery mixed the enzyme-treated material with the live R-strain bacteria. Finally, show another arrow pointing to live S-strain bacteria. Explain that transformation occurred. Repeat this drawing process to show the effects of an RNA-destroying enzyme. Finally, draw the process for a DNA-destroying enzyme. For this one, talk about why transformation did not occur and how Avery used this result to reach his conclusion that DNA is the transforming factor.

English Language Learners Introduce students to the term bacteriophage. Tell students that the word part -phage is based on the Greek word phagein, meaning “to eat.” Explain that when -phage is added to a noun, it signifies “one who eats.” Have students apply this knowledge to bacteriophage and discuss its meaning. (Students should conclude that bacteriophages “eat,” or destroy, the bacteria they infect.)

The Molecular Cause of Transformation In 1944, a group of scientists at the Rockefeller Institute in New York decided to repeat Griffith’s work. Led by the Canadian biologist Oswald Avery, the scientists wanted to determine which molecule in the heat-killed bacteria was most important for transformation. They reasoned that if they could find this particular molecule, it might reveal the chemical nature of the gene.

Avery and his team extracted a mixture of various molecules from the heat-killed bacteria. They carefully treated this mixture with enzymes that destroyed proteins, lipids, carbohydrates, and some other molecules, including the nucleic acid RNA. Transformation still occurred. Clearly, since those molecules had been destroyed, none of them could have been responsible for transformation.

Avery’s team repeated the experiment one more time. This time, they used enzymes that would break down a different nucleic acid—DNA. When they destroyed the DNA in the mixture, transformation did not occur. There was just one possible explanation for these results: DNA was the transforming factor. By observing bacterial transformation, Avery and other scientists discovered that the nucleic acid DNA stores and transmits genetic information from one generation of bacteria to the next.

Bacterial Viruses

What role did bacterial viruses play in identifying genetic material?

Scientists are a skeptical group. It usually takes several experiments to convince them of something as important as the chemical nature of the gene. The most important of the experiments relating to the discovery made by Avery’s team was performed in 1952 by two American scientists, Alfred Hershey and Martha Chase. They collaborated in studying viruses—tiny, nonliving particles that can infect living cells.

Bacteriophages A bacteriophage is a kind of virus that infects bacteria. When a bacteriophage enters a bacterium, it attaches to the surface of the bacterial cell and injects its genetic information into it, as shown in Figure 12–2. The viral genes act to produce many new bacteriophages, which gradually destroy the bacterium. When the cell splits open, hundreds of new viruses burst out.

Check for Understanding

HAND SIGNALS

Ask students the following questions, and have them show a thumbs-up sign if they can answer a question, a thumbs-down sign if they cannot, or a waving-hand sign if they are unsure.

• What is bacterial transformation?
• What conclusion did Frederick Griffith draw from his experimental results?
• What conclusion did Oswald Avery draw from his experimental results?

ADJUST INSTRUCTION

If students are confused, have pairs work together to write a one-sentence response to each question.

Answers

FIGURE 12–2 Viruses are much smaller than bacteria.

FIGURE 12–2 Bacteriophages A bacteriophage is a type of virus that infects and kills bacteria. The top diagram shows a bacteriophage known as T4. The micrograph shows three T2 bacteriophages (green) invading an E. coli bacterium (gold).

Compare and Contrast How large are viruses compared with bacteria?
**The Hershey-Chase Experiment**  Hershey and Chase studied a bacteriophage that was composed of a DNA core and a protein coat. They wanted to determine which part of the virus—the protein coat or the DNA core—entered the bacterial cell. Their results would either support or disprove Avery’s finding that genes were made of DNA.

The pair grew viruses in cultures containing radioactive isotopes of phosphorus-32 ($^{32}$P) and sulfur-35 ($^{35}$S). This was a clever strategy, because proteins contain almost no phosphorus, and DNA contains no sulfur. Therefore, these radioactive substances could be used as markers, enabling the scientists to tell which molecules actually entered the bacteria, carrying the genetic information of the virus. If they found radioactivity from $^{35}$S in the bacteria, it would mean that the virus’s protein coat had been injected into the bacteria. If they found $^{32}$P, then the DNA core had been injected.

The two scientists mixed the marked viruses with bacterial cells. They waited a few minutes for the viruses to inject their genetic material. Next, they separated the viruses from the bacteria and tested the bacteria for radioactivity. Figure 12–3 shows the steps in this experiment. What were the results? Nearly all the radioactivity in the bacteria was from phosphorus ($^{32}$P), the marker found in DNA. Hershey and Chase concluded that the genetic material of the bacteriophage was indeed DNA, not protein. **Hershey and Chase’s experiment with bacteriophages confirmed Avery’s results,** convincing many scientists that DNA was the genetic material found in genes—not just in viruses and bacteria, but in all living cells.

**How Science Works**

**Radioisotopes—a Tool for Biologists**

Radioisotopes, or radioactive isotopes, are commonly used by biologists to study cell processes because they can be substituted into biochemical reactions without changing the chemistry of the reactions. Isotopes of an element contain the same number of protons but different numbers of neutrons in their nuclei. Radioisotopes are isotopes that have an unstable nucleus. For example, $^{32}$P is an isotope of phosphorus. $^{32}$P is not stable, so it “decays” into a more stable form. This decay is detected as radioactivity. Scientists studying a particular biochemical reaction that involves phosphorus can use $^{32}$P to monitor the reaction. Radioisotopes of many other elements also exist, giving biologists a wide range of these “tools” to work with.

**Lead a Discussion**

Begin a discussion on the Hershey-Chase experiment.

**Ask** What happens when a bacteriophage infects a bacterium? (*The bacteriophage injects its genetic material into the bacterium.*)

**Ask** What did the bacteriophage used by Hershey and Chase consist of? (*protein and DNA*)

**Ask** What question did Hershey and Chase seek to answer with their experiment? (*Does DNA or protein transmit genetic information?*)

**Differentiated Instruction**

**Struggling Students** To help students understand the Hershey-Chase experiment, walk them through the steps of how a bacteriophage infects a bacterium. As a class, construct a **Flowchart** that shows these steps. First, the bacteriophage attaches to the surface of the bacterium and injects its genetic information. Next, the viral genes are replicated, and many new bacteriophages are produced. Last, the bacterium splits open, and new viruses burst out.


**Answers**

**In Your Notebook** The independent variable is the substance that was labeled, DNA or protein. The dependent variable is the presence of radioactivity in the infected cell. An example of a control variable is the amount of time Hershey and Chase waited for the viruses to infect the bacteria.
Storing Information

The genetic material stores information needed by every living cell.

The Role of DNA

What is the role of DNA in heredity?

You might think that scientists would have been satisfied knowing that genes were made of DNA, but that was not the case at all. Instead, they wondered how DNA, or any molecule for that matter, could do the critical things that genes were known to do. The next era of study began with one crucial assumption. The DNA that makes up genes must be capable of storing, copying, and transmitting the genetic information in a cell. These three functions are analogous to the way in which you might share a treasured book, as pictured in Figure 12–4.

Storing Information

The foremost job of DNA, as the molecule of heredity, is to store information. The genes that make a flower purple must somehow carry the information needed to produce purple pigment. Genes for blood type and eye color must have the information needed for their jobs as well, and other genes have to do even more. Genes control patterns of development, which means that the instructions that cause a single cell to develop into an oak tree, a sea urchin, or a dog must somehow be written into the DNA of each of these organisms.

Copying Information

Before a cell divides, it must make a complete copy of every one of its genes. To many scientists, the most puzzling aspect of DNA was how it could be copied. The solution to this and other puzzles had to wait until the structure of the DNA molecule became known. Within a few weeks of this discovery, a copying mechanism for the genetic material was put forward. You will learn about this mechanism later in the chapter.

The main functions of DNA presented in this lesson (storing information, copying information, and transmitting information). Have students use this list to remind them of DNA’s basic functions as they learn more about DNA’s structure and replication in this chapter.
Copying Information  
Before a cell divides, its genetic information must be copied.

Transmitting Information  
When a cell divides, each daughter cell must receive a complete copy of the genetic information.

Transmitting Information  
As Mendel's work had shown, genes are transmitted from one generation to the next. Therefore, DNA molecules must be carefully sorted and passed along during cell division. Such careful sorting is especially important during the formation of reproductive cells in meiosis. Remember, the chromosomes of eukaryotic cells contain genes made of DNA. The loss of any DNA during meiosis might mean a loss of valuable genetic information from one generation to the next.

12.1 Assessment

Review Key Concepts

1. **a. Review** List the conclusions that Griffith and Avery drew from their experiments.
   **b. Identify Variables** What was the experimental variable that Avery used when he repeated Griffith's work?

2. **a. Review** What conclusion did Hershey and Chase draw from their experiments?
   **b. Infer** Why did Hershey and Chase grow viruses in cultures that contained both radioactive phosphorus and radioactive sulfur? What might have happened if they had used only one radioactive substance?

3. **a. Review** What are the three key roles of DNA?
   **b. Apply Concepts** Why would the storage of genetic information in genes help explain why chromosomes are separated so carefully during mitosis?

Assessment Answers

1a. Griffith concluded that a heritable substance transforms harmless bacteria into harmful bacteria. Avery found that this heritable substance is DNA.

1b. The experimental variable in Avery’s experiment was the type of molecule-destroying enzyme he used.

2a. Hershey and Chase concluded that DNA is the genetic material found in genes.

2b. Growing viruses in separate cultures that contained both radioactive sulfur and radioactive phosphorus ensured that one sample of the virus had radioactive protein and the other sample had radioactive DNA. If only one type of molecule had been marked, they would not have been able to detect both types of molecule, and the results would not have been conclusive.

3a. Storing, copying, and transmitting genetic information.

3b. During mitosis, the cell’s DNA is replicated, and each daughter cell receives a copy. If the chromosomes do not separate correctly, the information they carry in DNA might not be passed correctly to the daughter cells.

4. Students’ flowcharts should describe the work of Griffith, Avery, or Hershey and Chase, including their procedures and conclusions.
LESSON 12.2

The Structure of DNA

THINK ABOUT IT
It's one thing to say that the molecule called DNA carries genetic information, but it would be quite another thing to explain how it could do this. DNA must not only specify how to assemble proteins, but how genes can be replicated and inherited. DNA has to be a very special molecule, and it's got to have a very special structure. As we will see, understanding the structure of DNA has been the key to understanding how genes work.

The Components of DNA

Deoxyribonucleic acid, or DNA, is a unique molecule indeed.

DNA is a nucleic acid made up of nucleotides joined into long strands or chains by covalent bonds. Let's examine each of these components more closely.

Nucleic Acids and Nucleotides

As you may recall, nucleic acids are long, slightly acidic molecules originally identified in cell nuclei. Like many other macromolecules, nucleic acids are made up of smaller subunits, linked together to form long chains. Nucleotides are the building blocks of nucleic acids. Figure 12–5 shows the nucleotides in DNA. These nucleotides are made up of three basic components: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous base.

Nitrogenous Bases and Covalent Bonds

Nitrogenous bases, simply put, are bases that contain nitrogen. DNA has four kinds of nitrogenous bases: adenine (\(\text{A}\)), guanine (\(\text{G}\)), cytosine (\(\text{C}\)), and thymine (\(\text{T}\)). The nucleotides in a strand of DNA are joined by covalent bonds formed between the sugar of one nucleotide and the phosphate group of the next. The nitrogenous bases stick out sideways from the nucleotide chain. The nucleotides can be joined together in any order, meaning that any sequence of bases is possible. These bases, by the way, have a chemical structure that makes them especially good at absorbing ultraviolet (UV) light. In fact, we can determine the amount of DNA in a solution by measuring the amount of light it absorbs at a wavelength of 260 nanometers (nm), which is in the UV region of the electromagnetic spectrum.

Understanding the Structure of DNA

Deoxyribonucleic acid, or DNA, is a nucleic acid made up of nucleotides joined into long strands or chains by covalent bonds. Let's examine each of these components more closely.

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If you don’t see much in Figure 12–5 that could explain the remarkable properties of DNA, don’t be surprised. In the 1940s and early 1950s, the leading biologists in the world thought of DNA as little more than a string of nucleotides. They were baffled, too. The four nucleotides, like the 26 letters of the alphabet, could be strung together in many different sequences, so it was possible they could carry coded genetic information. However, so could many other molecules, at least in principle. Biologists wondered if there were something more to the structure of DNA.

Solving the Structure of DNA

Knowing that DNA is made from long chains of nucleotides was only the beginning of understanding the structure of this molecule. The next step required an understanding of the way in which those chains are arranged in three dimensions.

Chargaff’s Rule One of the puzzling facts about DNA was a curious relationship between its nucleotides. Years earlier, Erwin Chargaff, an Austrian-American biochemist, had discovered that the percentages of adenine [A] and thymine [T] bases are almost equal in any sample of DNA. The same thing is true for the other two nucleotides, guanine [G] and cytosine [C]. The observation that \([A] = [T]\) and \([G] = [C]\) became known as “Chargaff’s rule.” Despite the fact that DNA samples from organisms as different as bacteria and humans obeyed this rule, neither Chargaff nor anyone else had the faintest idea why.

### Base Percentages

In 1949, Erwin Chargaff discovered that the relative amounts of A and T, and of G and C, are almost always equal. The table shows a portion of the data that Chargaff collected.

<table>
<thead>
<tr>
<th>Source of DNA</th>
<th>A</th>
<th>T</th>
<th>G</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streptococcus</td>
<td>29.8</td>
<td>31.6</td>
<td>20.5</td>
<td>18.0</td>
</tr>
<tr>
<td>Yeast</td>
<td>31.3</td>
<td>32.9</td>
<td>18.7</td>
<td>17.1</td>
</tr>
<tr>
<td>Herring</td>
<td>27.8</td>
<td>27.5</td>
<td>22.2</td>
<td>22.6</td>
</tr>
<tr>
<td>Human</td>
<td>30.9</td>
<td>29.4</td>
<td>19.9</td>
<td>19.8</td>
</tr>
<tr>
<td>E.coli</td>
<td>24.7</td>
<td>23.6</td>
<td>26.0</td>
<td>25.7</td>
</tr>
</tbody>
</table>

### PLANNING

1. **Interpret Tables** Which organism has the highest percentage of adenine?

2. **Calculate** If a species has 35% thymine in its DNA, what is the percentage of the other three bases?

3. **Draw Conclusions** What did the fact that A and T, and G and C, occurred in equal amounts suggest about the relationship among these bases?

### DIFFERENTIATED INSTRUCTION

**ELL** English Language Learners Draw an enlarged, unlabeled copy of Figure 12–5 on the board. Provide students with index cards on which are written: covalent bond, nucleotide, phosphate group, deoxyribose, adenine, guanine, cytosine, and thymine. Point to a structure in the diagram, and have students hold up the correct card. Then, have them pronounce the term aloud.

**LPR** Less Proficient Readers Help students locate the information in the text that describes nucleic acids, nucleotides, nitrogenous bases, and covalent bonds. Then, show students how Figure 12–5 can be used to visualize each of these terms.

### ANALYZING DATA

**PURPOSE** Students will analyze data to determine the percentages of the four nitrogenous bases in the DNA of four different organisms.

**PLANNING** Remind students that A, G, C, and T are the abbreviations often used by biologists for adenine, guanine, cytosine, and thymine. Point out that these four bases are the only nitrogenous bases found in DNA.

**ANSWERS**

1. yeast
2. 35% thymine and 15% each of guanine and cytosine
3. It suggested that A is paired with T and G with C in some way.

**FIGURE 12–5** The nucleotides in a strand of DNA are joined by covalent bonds formed between their sugar and phosphate groups.
Have students examine Figure 12–6, and then divide the class into three groups. Assign one of the following scientists or teams to each group: Chargaff, Franklin, and Watson and Crick. Have each group prepare a short presentation describing the contributions of its assigned scientist(s). Ask each group to share its presentation with the class.

DIFFERENTIATED INSTRUCTION

**ELL Advanced Learners** As students are preparing the presentations described above, have advanced learners do additional research to prepare a short report about the Nobel Prize that was awarded to Watson, Crick, and Wilkins for their work on DNA’s structure. Have them learn more about why Maurice Wilkins was included in the prize but Rosalind Franklin was not. Have students share this information when the group reports are presented.

**Focus on ELL: Access Content**

**ALL SPEAKERS** Have students fold a sheet of paper into thirds to organize the information about Chargaff, Franklin, and Watson and Crick. At the top of each section, have students record the name of the scientist or scientist team. Then, suggest beginning and intermediate speakers make bulleted lists of words or phrases that will help them recall the contributions of each scientist or team. Encourage advanced students to record the information in complete sentences. Require advanced high students to write full, complex sentences that accurately summarize the scientists’ work.

**Build Vocabulary**

**Academic Words** In biochemistry, the noun helix refers to an extended spiral chain of units in a protein, nucleic acid, or other large molecule. The plural term is helices.

**Franklin’s X-Rays** In the early 1950s, the British scientist Rosalind Franklin began to study DNA. Franklin used a technique called X-ray diffraction to get information about the structure of the DNA molecule. First, she purified a large amount of DNA, then stretched the DNA fibers in a thin glass tube so that most of the strands were parallel. Next, she aimed a powerful X-ray beam at the concentrated DNA samples and recorded the scattering pattern of the X-rays on film. Franklin worked hard to obtain better and better patterns from DNA until the patterns became clear. The result of her work is the X-ray photograph shown in Figure 12–6, taken in the summer of 1952.

By itself, Franklin’s X-ray pattern does not reveal the structure of DNA, but it does carry some very important clues. The X-shaped pattern shows that the strands in DNA are twisted around each other like the coils of a spring, a shape known as a helix. The angle of the X suggests that there are two strands in the structure. Other clues suggest that the nitrogenous bases are near the center of the DNA molecule.

**The Work of Watson and Crick** While Franklin was continuing her research, James Watson, an American biologist, and Francis Crick, a British physicist, were also trying to understand the structure of DNA. They built three-dimensional models of the molecule that were made of cardboard and wire. They twisted and stretched the models in various ways, but their best efforts did nothing to explain DNA’s properties.

Then, early in 1953, Watson was shown a copy of Franklin’s remarkable X-ray pattern. The effect was immediate. In his book *The Double Helix*, Watson wrote: “The instant I saw the picture my mouth fell open and my pulse began to race.”

**Check for Understanding**

**FOLLOW-UP PROBES**

Ask: How is solving the puzzle of DNA’s structure an example of a collection of discoveries by different scientists? *(Although Watson and Crick are remembered as the team that solved the structure of DNA, their work would not have been possible without the work of many other scientists, including those described in this lesson.)*

**ADJUST INSTRUCTION**

Use the following demonstration to help students understand the key roles played by scientists other than Watson and Crick to determine DNA’s structure. Open a box containing the pieces of a jigsaw puzzle. Hand one piece of the puzzle to each of four or five students. Point out that the puzzle could not be completed without the pieces held by those students. In the same way, the puzzle of DNA’s structure was solved because many individuals supplied a “piece of the puzzle.”
The clues in Franklin's X-ray pattern enabled Watson and Crick to build a model that explained the specific structure and properties of DNA. The pair published their results in a historic one-page paper in April of 1953, when Franklin's paper describing her X-ray work was also published. Watson and Crick's breakthrough model of DNA was a double helix, in which two strands of nucleotide sequences were wound around each other.

**The Double-Helix Model**

What does the double-helix model tell us about DNA?

A double helix looks like a twisted ladder. In the double-helix model of DNA, the two strands twist around each other like spiral staircases. Watson and Crick realized that the double helix accounted for Franklin’s X-ray pattern. Further still, it explained many of the most important properties of DNA. The double-helix model explains Chargaff’s rule of base pairing and how the two strands of DNA are held together. This model can even tell us how DNA can function as a carrier of genetic information.

Antiparallel Strands One of the surprising aspects of the double-helix model is that the two strands of DNA run in opposite directions. In the language of biochemistry, these strands are “antiparallel.” This arrangement enables the nitrogenous bases on both strands to come into contact at the center of the molecule. It also allows each strand of the double helix to carry a sequence of nucleotides, arranged almost like letters in a four-letter alphabet.

**In Your Notebook**

Draw and label your own model of the DNA double-helix structure.

Quick Facts

**THE STRUCTURE OF DNA**

When Watson and Crick were ready to announce their double-helix model in 1953, they made a drawing of DNA and sent it with a letter to Nature, a highly respected scientific journal. Nature routinely publishes “letters,” which are much shorter than typical scientific papers. The second and third paragraphs of Watson and Crick’s letter explained why they believed a triple-helix model of DNA, which was being developed by Linus Pauling and other researchers, was incorrect. The letter then proceeded to describe the double-helix model of DNA. They ended the letter by writing, “It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.” Within a few weeks, Nature published Watson and Crick’s description of the copying mechanism. Their classic paper, titled “A Structure for Deoxyribose Nucleic Acid,” appeared in the April 25, 1953 issue of the journal.

**Use Models**

Show the class a physical model of a DNA molecule. Point out to students that a double helix looks like a twisted ladder.

**Ask** If a twisted ladder is used as a model of DNA, which parts of a DNA molecule correspond to the sides of the ladder? (the phosphate group and the 5-carbon sugar deoxyribose)

**Ask** Which parts of a DNA molecule correspond to the rungs of the ladder? (nitrogenous base pairs)

**DIFFERENTIATED INSTRUCTION**

**Special Needs**

Draw a picture of a ladder on the board. Explain how the ladder can model the structure of DNA. Label the rungs of the ladder Nitrogenous Bases and the sides of the ladder Sugar and Phosphate Groups. Ask students to imagine what the ladder would look like if it were twisted. Then, show them a physical model of DNA. Help them make the connection between the ladder drawing and the DNA model by pointing out the nitrogenous bases, phosphate groups, and sugar molecules.

Students should infer that exposure to UV light may interfere with proper base pairing in the DNA of skin cells. Students can go online to Biology.com to gather their evidence.

**Answers**

**IN YOUR NOTEBOOK**

Students’ models should depict DNA as a double helix, with labels identifying the nitrogenous bases, deoxyribose, and phosphate groups.
**Assess and RemEDIATE**

**EVALUATE UNDERSTANDING**

Read the first Key Question for this lesson to the class. Then, ask a volunteer to provide an answer. Continue until each of the three Key Questions has been answered. Then, have students complete the 12.2 Assessment.

**REMEDIATION SUGGESTION**

**LS Struggling Students** If students have difficulty answering Question 1b, remind them that hydrogen bonds are a type of weak chemical bond.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

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**Assessment Answers**

1a. 5-carbon sugar molecules, phosphate groups, four different nitrogenous bases

1b. Hydrogen bonds hold the paired nitrogenous bases together. Because hydrogen bonds are weak bonds, the two strands of DNA are easily separated—a characteristic that is important to DNA's function.

2a. Chargaff determined that, in a double-stranded DNA molecule, adenine and thymine are present in equal proportions and guanine and cytosine are present in equal proportions. Franklin’s X-ray photographs of DNA revealed a spiral structure. Both of these findings helped Watson and Crick understand DNA's double helix and complementary base pairing.

2b. DNA is too small to be examined with a light microscope—the only kind of microscope available at the time.

3a. Watson and Crick’s model is composed of two antiparallel strands that are connected by hydrogen bonds between nitrogenous bases. Hydrogen bonds form between adenine and thymine and between cytosine and guanine.

3b. Watson and Crick’s model depicted DNA as a double helix with adenine and thymine paired together. This pairing accounts for the equal amounts of thymine and adenine in DNA.

**VISUAL THINKING**

4. Students’ models should show the structure of DNA as a double helix and include correct base pairing between adenine and thymine and between cytosine and guanine.
Discovering the Role of DNA  Genes and the principles of genetics were discovered before scientists identified the molecules that genes are made of. With the discovery of DNA, scientists have been able to explain how genes are replicated and how they function.

Gregor Mendel shows that the characteristics of pea plants are passed along in a predictable way. His discovery begins the science of genetics.

Walter Sutton shows that chromosomes carry the cell's units of inheritance.

Thomas Hunt Morgan demonstrates that genes are arranged in linear fashion on the chromosomes of the fruit fly.

Frederick Griffith discovers that bacteria contain a molecule that can transfer genetic information from cell to cell.

Oswald Avery, Colin Macleod, and Maclyn McCarty show the substance that Griffith discovered is DNA.

Erwin Chargaff analyzes the base composition of DNA in cells. He discovers that the amounts of adenine and thymine are almost always equal, as are the amounts of guanine and cytosine.

Alfred Hershey and Martha Chase confirm that the genetic material of viruses is DNA, not protein.

Rosalind Franklin records a critical X-ray diffraction pattern, demonstrating that DNA is in the form of a helix.

James Watson and Francis Crick publish their model of the DNA double helix. The model was made possible by Franklin's work.

Craig Venter and Francis Collins announce the draft DNA sequence of the human genome at a White House ceremony in Washington, D.C. The final version is published in 2003.

In 1950, Erwin Chargaff analyzes the base composition of DNA in cells. He discovers that the amounts of adenine and thymine are almost always equal, as are the amounts of guanine and cytosine.

1965

1860 1880 1900 1920 1940 1960 1980 2000

1865
Gregor Mendel shows that the characteristics of pea plants are passed along in a predictable way. His discovery begins the science of genetics.

1903
Walter Sutton shows that chromosomes carry the cell's units of inheritance.

1911
Thomas Hunt Morgan demonstrates that genes are arranged in linear fashion on the chromosomes of the fruit fly.

1928
Frederick Griffith discovers that bacteria contain a molecule that can transfer genetic information from cell to cell.

1944
Oswald Avery, Colin Macleod, and Maclyn McCarty show the substance that Griffith discovered is DNA.

1950
Erwin Chargaff analyzes the base composition of DNA in cells. He discovers that the amounts of adenine and thymine are almost always equal, as are the amounts of guanine and cytosine.

1952
Alfred Hershey and Martha Chase confirm that the genetic material of viruses is DNA, not protein.

1953
James Watson and Francis Crick publish their model of the DNA double helix. The model was made possible by Franklin's work.

2000
Craig Venter and Francis Collins announce the draft DNA sequence of the human genome at a White House ceremony in Washington, D.C. The final version is published in 2003.

How Science Works

SCIENTISTS ARE A SKEPTICAL BUNCH

Today, it seems clear that Avery's results had shown without a doubt that DNA makes up genes. However, in 1944 the results were questionable. Then, inheritance in bacteria was just beginning to be studied. Scientists didn’t know whether bacteria had genes like those in more complex organisms. And even if DNA were the hereditary substance in bacteria, it might not be the hereditary substance in more complex organisms. DNA was still considered a very simple molecule. Scientists were more satisfied with Hershey and Chase's results with bacteriophages in 1952. By that time, genetic studies showed that bacteriophages had properties of heredity similar to those of more complex organisms. Also, experiments showed that DNA was more complex than originally thought.

Teach

Lead a Discussion

Have students examine the time line to learn more about the history of genetics research. Ask them questions to make sure they understand the information presented on the page.

Ask How many years passed between the work of Mendel and the announcement of the draft of the human genome? (135 years)

Ask What did Walter Sutton find? (Walter Sutton found that the chromosomes carry genes.)

Ask How does Rosalind Franklin’s work illustrate the connection between technology and science? (Rosalind Franklin’s work would not have been possible without X-ray diffraction technology.)

DIFFERENTIATED INSTRUCTION

Struggling Students Have students take turns reading aloud the time line entries, moving in chronological order. After each entry has been read, have a brief discussion of the significance of the discovery.

Advanced Students Explain that the most recent entry on the time line, the sequencing of the human genome, is a project that built on all of the previous discoveries in the time line. Have students imagine a future entry for the time line, based on what they know about genetics and what they envision as future applications of genetics. Have each student share his or her imagined time line entry with the class.

Answers

WRITING

Students’ responses will vary based on their research. Students might note that both Watson and Crick went on to research how DNA controls protein synthesis.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP II, V

CONTENT C.2.a, G.1, G.3

INQUIRY A.2.a
Getting Started

Objectives
12.3.1 Summarize the events of DNA replication.
12.3.2 Compare DNA replication in prokaryotes with that of eukaryotes.

Student Resources
Study Workbooks A and B, 12.3 Worksheets
Spanish Study Workbook, 12.3 Worksheets
Lab Manual B, 12.2 Hands-On Activity

Build Background
Have students suggest ways to make a copy of a page of the text. (Sample answers: by hand, by using a copier) Ask them why it is important to make an exact copy. (So the information doesn’t change) Explain that cells copy DNA in a process called DNA replication.

Answers
IN YOUR NOTEBOOK Sample answer: DNA separates into two strands and produces two new complementary strands by the rules of base pairing.

Unifying Concepts and Processes
I, V

Content
C.2.a, C.2.c

Inquiry
A.1.b, A.1.d

DNA Replication

THINK ABOUT IT Before a cell divides, its DNA must first be copied. How might the double-helix structure of DNA make that possible? What might happen if one of the nucleotides were damaged or chemically altered just before the copying process? How might this affect the DNA inherited by each daughter cell after cell division?

Copying the Code

What role does DNA polymerase play in copying DNA?

When Watson and Crick discovered the structure of DNA, they immediately recognized one genuinely surprising aspect of the structure. Base pairing in the double helix explains how DNA can be copied, or replicated, because each base on one strand pairs with one—and only one—base on the opposite strand. Each strand of the double helix therefore has all the information needed to reconstruct the other half by the mechanism of base pairing. Because each strand can be used to make the other strand, the strands are said to be complementary.

The Replication Process Before a cell divides, it duplicates its DNA in a copying process called replication. This process, which occurs during late interphase of the cell cycle, ensures that each resulting cell has the same complete set of DNA molecules. During replication, the DNA molecule separates into two strands and then produces two new complementary strands following the rules of base pairing. Each strand of the double helix of DNA serves as a template, or model, for the new strand.

Figure 12–8 shows the process of DNA replication. The two strands of the double helix have separated, or “unzipped,” allowing two replication forks to form. As each new strand forms, new bases are added following the rules of base pairing. If the base on the old strand is adenine, then thymine is added to the newly forming strand. Likewise, guanine is always paired to cytosine. For example, a strand that has the base sequence TAGGTT produces a strand with the complementary base sequence ATGCAA. The result is two DNA molecules identical to each other and to the original molecule. Note that each DNA molecule resulting from replication has one original strand and one new strand.

In Your Notebook In your own words, describe the process of DNA replication.

Teach for Understanding

Enduring Understanding DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

Guiding Question How do cells copy their DNA?

Evidence of Understanding After completing the lesson, give students the following assessment to show they understand how cells copy their DNA. Have students work in small groups to make a series of three diagrams. The first diagram should show a labeled 15-base section of double-stranded DNA. The second diagram should show what the DNA would look like during the replication process. The third diagram should show the results of replication. Remind students to label each nitrogenous base and to follow the rules of base pairing.
DNA replication is carried out by a series of enzymes. These enzymes first “unzip” a molecule of DNA by breaking the hydrogen bonds between base pairs and unwinding the two strands of the molecule. Each strand then serves as a template for the attachment of complementary bases. You may recall that enzymes are proteins with highly specific functions. For this reason, they are often named for the reactions they catalyze. The principal enzyme involved in DNA replication is called **DNA polymerase**. **DNA polymerase** is an enzyme that joins individual nucleotides to produce a new strand of DNA. Besides producing the sugar-phosphate bonds that join nucleotides together, DNA polymerase also “proofreads” each new DNA strand, so that each molecule is a near-perfect copy of the original.

**FIGURE 12–8 DNA Replication**
During DNA replication, the DNA molecule produces two new complementary strands. Each strand of the double helix serves as a template for the new strand. The micrograph shows a pair of replication forks in human DNA.

Apply Concepts What makes the new DNA strand complementary to the original strand?

**DIFFERENTIATED INSTRUCTION**

**L1 Struggling Students** Write the following sentence starters on the board.
- During replication, DNA polymerase...
- At the replication fork, ...
- During replication, each original DNA strand...

Ask students to write a phrase to complete each sentence. Then, ask volunteers to share their responses with the class.

**L3 Advanced Students** Explain to advanced students that enzymes are critical to the process of DNA replication, just as they are to most chemical reactions in living things. Have students find the name of, and learn more about, the enzyme that unwinds and unzips DNA during replication. (helicase) Ask them to share their findings with the class.

Have students discuss what might happen if a UV-induced base change was copied during the process of DNA replication. Students can go online to **Biology.com** to gather their evidence.

Students can watch an animated version of DNA replication by accessing **Inter-Active Art: DNA Replication**.

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**How Science Works**

**THE DISCOVERY OF DNA POLYMERASE**
In 1959, Arthur Kornberg, a researcher in the field of enzymology, won a Nobel Prize for the discovery of DNA polymerase. This groundbreaking work was summarized in two scientific papers. The first paper described the extraction and purification of DNA polymerase from bacteria; the second paper described an analysis of the substances required for DNA synthesis, including DNA polymerase. These two papers were submitted to the *Journal of Biological Chemistry* in 1957. Both papers were initially rejected. After intervention by a newly hired editor-in-chief, the papers were published in 1958.

**Answers**

**FIGURE 12–8** The new DNA strand is complementary to the original strand because its base sequence is determined by the rules of base pairing.
LESSON 12.3

Teach continued

Build Reading Skills
Point out the head Replication in Living Cells. Have students use this head to start an outline of the material in this section. Show them how to incorporate the two subheads for prokaryotic and eukaryotic DNA replication. After students have completed their outlines, ask volunteers to share them with the class.

DIFFERENTIATED INSTRUCTION

ELL Less Proficient Readers Encourage struggling readers to work in small groups to prepare the outline of the information in this section, as described above. Students can divide the reading among members of the group and share what they learn to create the outline.

Focus on ELL: Build Background
ALL SPEAKERS Divide students into four groups of mixed speaking levels. Then, have them complete a Gallery Walk activity. Ask the groups to rotate between four locations in the classroom where you have posted questions about lesson content, such as “What happens during DNA replication?” or “What does DNA polymerase do?” At each location, have an intermediate or advanced speaker read the question aloud. Then, ask beginning speakers to give a short oral response to the question. Have advanced high speakers prepare a written response in the form of at least one complete, complex sentence. Groups should also read, evaluate, and comment on any of the previous groups’ answers.

Study Wkbks A/B, Appendix S6, Gallery Walk.

Quick Lab

Modeling DNA Replication
1. Cut out small squares of white and yellow paper to represent phosphate and sugar molecules. Then, cut out small strips of blue, green, red, and orange paper to represent the four nitrogenous bases. Build a set of five nucleotides using your paper strips and tape. Look back at Figure 12–5 if you need help.
2. Using your nucleotides, tape together a single strand of DNA. Exchange strands with a partner.

Telomeres DNA at the tips of chromosomes are known as telomeres (Figure 12–9). This DNA is particularly difficult to replicate. Cells use a special enzyme, called telomerase, to solve this problem by adding short, repeated DNA sequences to the telomeres. In rapidly dividing cells, such as stem cells and embryonic cells, telomerase helps to prevent genes from being damaged or lost during replication. Telomerase is often switched off in adult cells. In cancer cells, however, telomerase may be activated, enabling these cells to grow and proliferate rapidly.

Replication in Living Cells
How does DNA replication differ in prokaryotic cells and eukaryotic cells?
DNA replication occurs during the S phase of the cell cycle. As we saw in Chapter 10, replication is carefully regulated, along with the other critical events of the cycle so that it is completed before a cell enters mitosis or meiosis. But where, exactly, is DNA found inside a living cell?
The cells of most prokaryotes have a single, circular DNA molecule in the cytoplasm, containing nearly all the cell’s genetic information. Eukaryotic cells, on the other hand, can have up to 1000 times more DNA. Nearly all of the DNA of eukaryotic cells is found in the nucleus, packaged into chromosomes. Eukaryotic chromosomes consist of DNA, tightly packed together with proteins to form a substance called chromatin. Together, the DNA and histone molecules form beadlike structures called nucleosomes, as described in Chapter 10. Histones, you may recall, are proteins around which chromatin is tightly coiled.
Prokaryotic DNA Replication  In most prokaryotes, DNA replication does not start until regulatory proteins bind to a single starting point on the chromosome. These proteins then trigger the beginning of the S phase, and DNA replication begins. Replication in most prokaryotic cells starts from a single point and proceeds in two directions until the entire chromosome is copied. This process is shown in Figure 12–10. Often, the two chromosomes produced by replication are attached to different points inside the cell membrane and are separated when the cell splits to form two new cells.

Eukaryotic DNA Replication  Eukaryotic chromosomes are generally much bigger than those of prokaryotes. In eukaryotic cells, replication may begin at dozens or even hundreds of places on the DNA molecule, proceeding in both directions until each chromosome is completely copied. Although a number of proteins check DNA for chemical damage or base pair mismatches prior to replication, the system is not foolproof. Damaged regions of DNA are sometimes replicated, resulting in changes to DNA base sequences that may alter certain genes and produce serious consequences.

The two copies of DNA produced by replication in each chromosome remain closely associated until the cell enters prophase of mitosis. At that point, the chromosomes condense, and the two chromatids in each chromosome become clearly visible. They separate from each other in anaphase of mitosis, as described in Chapter 10, producing two cells, each with a complete set of genes coded in DNA.

1. a. Review  How is DNA replicated?
   b. Apply Concepts  What is the role of DNA polymerase in DNA replication?

2. a. Review  Where and in what form is prokaryotic DNA found? Where is eukaryotic DNA found?
   b. Infer  What could be the result of damaged DNA being replicated?

3. Make a Venn diagram that compares the process of DNA replication in prokaryotes and eukaryotes. Compare the location, steps, and end products of the process in each kind of cell.

Assessment Answers

1a. The DNA molecule separates into two strands at the replication fork. Each individual strand is then used as a template for the attachment of complementary bases.

1b. DNA polymerase joins individual nucleotides to produce a new strand of DNA and proofreads each new strand.

2a. DNA in prokaryotic cells is found in the form of a single circular chromosome in the cytoplasm; DNA in eukaryotic cells is found in the nucleus, packaged into bigger, individual chromosomes.

2b. If damaged DNA is replicated, the cell that receives it may have altered genes, which could lead to serious consequences.

3. Students’ Venn diagrams should include for prokaryotic replication only: occurs in the cytoplasm, DNA arranged in a single circular chromosome, starts at just one point and continues around the circle until it is completed; for eukaryotic replication only: occurs in the nucleus, begins at several points on the DNA molecule; for both: DNA polymerase joins nucleotides, new DNA strands are complementary to the strands they were made from.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Extracting DNA described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Students should wear safety goggles while performing this lab. Have students wash their hands when they complete the lab. Students should use caution with glassware and follow the lab instructions exactly.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 300.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP I
CONTENT C.2.a
INQUIRY A.1.b

Pre-Lab Answers

BACKGROUND QUESTIONS

a. In DNA nucleotides are joined together in long strands by covalent bonds. A double helix structure forms when two antiparallel strands twist around each other.

b. hydrogen bonds

c. Because hydrogen bonds are relatively weak, the strands of DNA can separate and be replicated.

PRE-LAB QUESTIONS

1. Sample answer: Strawberry cells need DNA to produce the proteins that control reactions within its cells.

2. The clump of DNA will contain DNA from many cells.

3. Sample answer: The solid DNA will be made up of thin long threads. The solid will be flexible rather than rigid.

4. Measure the mass of the strawberry and the mass of the extracted DNA. Divide the mass of the DNA by the mass of the strawberry.
12 Study Guide

**Big ideas Information and Heredity, Cellular Basis of Life**

DNA is a double-stranded protein molecule made up of nucleotide base pairs. DNA stores, copies, and transmits the genetic information in a cell.

### 12.1 Identifying the Substance of Genes

- By observing bacterial transformation, Avery and other scientists discovered that the nucleic acid DNA stores and transmits genetic information from one generation of bacteria to the next.
- Hershey and Chase’s experiment with bacteriophages confirmed Avery’s results, convincing many scientists that DNA was the genetic material found in genes—not just in viruses and bacteria, but in all living cells.
- The DNA that makes up genes must be capable of storing, copying, and transmitting the genetic information in a cell.

**transformation (339) bacteriophage (340)**

### 12.2 The Structure of DNA

- DNA is a nucleic acid made up of nucleotides joined into long strands or chains by covalent bonds.
- The clues in Franklin’s X-ray pattern enabled Watson and Crick to build a model that explained the specific structure and properties of DNA.
- The double-helix model explains Chargaff’s rule of base pairing and how the two strands of DNA are held together.

**base pairing (348)**

### 12.3 DNA Replication

- DNA polymerase is an enzyme that joins individual nucleotides to produce a new strand of DNA.
- Replication in most prokaryotic cells starts from a single point and proceeds in two directions until the entire chromosome is copied.
- In eukaryotic cells, replication may begin at dozens or even hundreds of places on the DNA molecule, proceeding in both directions until each chromosome is completely copied.

**replication (350) telomere (351)**

**DNA polymerase (351)**

**Think Visually** Using the information in this chapter, complete the following concept map about DNA replication:

- In Prokaryotes
  - starts at
  - and proceeds
- In Eukaryotes
  - starts at
  - and proceeds
  - The sites where replication occurs are called
  - replication forks

---

### Performance Tasks

**SUMMATIVE TASK** Tell students to imagine they have been hired as tutors to teach this chapter to a group of students. Have them work in small groups to create a slide presentation that could be used to teach chapter content. Each presentation should consist of at least ten slides of text and graphics. Tell students their presentation must convey information about each lesson Key Question. Have groups share their presentations with the class.

**TRANSFER TASK** Have students imagine they are either James Watson or Francis Crick. The year is 1953, and Watson and Crick have just submitted their paper describing DNA’s structure to the journal *Nature*. In their role as Watson or Crick, have students write a letter to a friend explaining the model of DNA. The letter should also describe the work of at least three other scientists whose work influenced the development of the model.

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### Answers

**THINK VISUALLY**

1. a single point
2. dozens or even hundreds of places
3. in both directions
4. in both directions
5. replication forks

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**Study Online**

**REVIEW AND ASSESSMENT RESOURCES**

**Editable Worksheets** Pages of Study Workbooks A and B, Lab Manuals A and B, and the Assessment Resources Book are available online. These documents can be easily edited using a word-processing program.

**Lesson Overview** Have students reread the Lesson Overviews to help them study chapter concepts.

**Vocabulary Review** The *Flash Cards* and *Match It* provide an interactive way to review chapter vocabulary.

**Chapter Assessment** Have students take an online version of the Chapter 12 Assessment.

**Standardized Test Prep** Students can take an online version of the Standardized Test Prep. You will receive their scores along with ideas for remediation.

**Diagnostic and Benchmark Tests** Use these tests to monitor your students’ progress and supply remediation.
Lesson 12.1

UNDERSTAND KEY CONCEPTS

1. b  2. d  3. c  4. b

5. A chemical factor can be transferred from dead bacteria to living bacteria that can change the heritable characteristics of the living bacteria.

6. DNA contains phosphorus, but protein does not. Protein contains sulfur, but DNA does not. This allowed radioactive phosphorus and radioactive sulfur to identify each molecule specifically.

THINK CRITICALLY

7. Griffith heated a culture of a disease-causing strain of bacteria, which killed the bacteria but did not destroy the DNA. When he mixed the heat-killed, disease-causing bacteria with live, harmless bacteria, the DNA from the disease-causing bacteria was transferred to the live bacteria. These bacteria and their offspring caused pneumonia in the mice.

8. Avery and his team used enzymes to destroy various biological molecules. They showed that when DNA was destroyed, genetic information could not be transferred. Destroying other biological molecules did not have the same effect.

Lesson 12.2

UNDERSTAND KEY CONCEPTS

9. b  10. a  11. c

12. A nucleotide has three parts: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous base.

13. Chargaff’s rules of base pairing gave Watson and Crick confidence that their model was correct, because their model agreed with Chargaff’s observations of the relative percentages of A, T, G, and C in DNA.

14. The scattering pattern of X-rays sent through a sample of DNA showed that the molecule was helical and consisted of two strands.

15. The two strands of DNA are antiparallel, which means that the bases can line up in the two strands and form hydrogen bonds between the A–T and G–C pairs.

THINK CRITICALLY

16. The model showed that hydrogen bonds could create a nearly perfect fit between nitrogenous bases along the center of the molecule. But the bonds could only form between adenine and thymine, and guanine and cytosine.

17. Adenine and guanine are larger than cytosine and thymine. The equal distance between the backbones suggested that a small base must always be paired with a large base.

Lesson 12.3

UNDERSTAND KEY CONCEPTS

18. c  19. a  20. a  21. d

22. Base pairing is the principle that hydrogen bonds form only between certain base pairs: adenine and thymine, cytosine and guanine. In replication, base pairing ensures that the new complementary strands are identical to the original strands.

23. In a typical prokaryotic cell, DNA is found in the cytoplasm in a single circular chromosome.

24. DNA separates into two strands, then two new complementary strands are generated following the rules of base pairing. Each new DNA molecule has one strand from the original molecule and one newly synthesized strand, making each new DNA molecule an exact duplicate of the original.
**12.3 DNA Replication**

**Understand Key Concepts**

18. In prokaryotes, DNA molecules are located in the
   a. nucleus.    c. cytoplasm.
   b. ribosomes.  d. histones.

19. In eukaryotes, nearly all the DNA is found in the
   a. nucleus.    c. cytoplasm.
   b. ribosomes.  d. histones.

20. The diagram below shows the process of DNA
   a. replication. c. transformation.
   b. digestion.  d. transpiration.

21. The main enzyme involved in linking individual nucleotides into DNA molecules is
   a. DNA protease. c. carbohydrase.
   b. ribose.     d. DNA polymerase.

22. What is meant by the term base pairing? How is base pairing involved in DNA replication?

23. Describe the appearance of DNA in a typical prokaryotic cell.

24. Explain the process of replication. When a DNA molecule is replicated, how do the new molecules compare to the original molecule?

**Think Critically**

25. **Use Analogies** Is photocopying a document similar to DNA replication? Think of the original materials, the copying process, and the final products. Explain how the two processes are alike. Identify major differences.

26. **Compare and Contrast** Describe the similarities and differences between DNA replication in prokaryotic cells and in eukaryotic cells.

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**THINK CRITICALLY**

25. Photocopying a document is similar in some ways to DNA replication. In both processes, you start with one copy and end up with two identical copies. However, the copying process is different. In photocopying, the original is copied, so you end up with one original copy and one completely new copy. In DNA replication, the original molecule splits in half, so you end up with two copies that are half original and half new.

26. **Similarities**: DNA replication in both eukaryotes and prokaryotes proceeds in both directions and results in two identical strands of DNA. Differences: prokaryotic DNA replication occurs in the cytoplasm and begins at a single point on the chromosome; eukaryotic DNA replication occurs in the nucleus and begins in many places on a chromosome.

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**UV LIGHT**

The nucleotides in DNA include the nitrogenous bases adenine, cytosine, guanine, and thymine (A, C, G, and T). The energy from UV light can produce chemical changes in these bases, damaging the DNA molecule and producing errors when DNA is replicated.

1. **Predict** Use your understanding of the structure of DNA to predict what sorts of problems excessive UV light might produce in the DNA molecule. How might these changes affect the functions of DNA?

2. **Infer** All cells have systems of enzymes that repair UV-induced damage to their DNA. Some cellular systems block DNA replication if there are base pairing problems in the double helix. Why are these systems important? How might they work?

3. **Relate Cause and Effect** Analyze the effects that UV light might have on skin cells. Why is UV light so dangerous? Why is the skin particularly vulnerable to it?

4. **Connect to the Big Idea** Among humans who inherit genetic defects in their DNA-repair systems, the incidence of skin cancer is as much as 1000 times greater than average. Based on this information, what can you infer about the effect of UV light on DNA?

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**CHAPTER MYSTERY ANSWERS**

1. Sample answer: The energy from UV light can cause chemical changes in the bases. It might cause the formation of new bonds or the breaking of old ones, preventing the DNA molecule from replicating properly.

2. Sample answer: They are important because they prevent damaged DNA from passing along incorrect information when it replicates. They might work by disabling DNA polymerase.

3. UV light is dangerous because it can cause chemical changes in DNA. The skin is particularly vulnerable because it covers and protects most of the body and is the organ that is subject to the greatest exposure to UV light.

4. Sample answer: The fact that people with genetic defects in their DNA repair systems have a higher incidence of skin cancer, and the fact that excessive exposure to UV light causes skin cancer, provides evidence that for the effect of UV light on DNA—UV light damages DNA, and DNA damage is associated with cancer.

Have students watch the short video **DNA Super Sleuth** to see how scientists use DNA to solve crimes.
Connecting Concepts

USE SCIENCE GRAPHICS

27. about 260 nm

28. Ultraviolet light, particularly between 250 and 270 nm wavelengths, is harmful to living organisms.

29. Sample answer: As more ozone is destroyed, does the amount of UV radiation that reaches Earth’s surface increase?

WRITE ABOUT SCIENCE

30. Answers will vary. In their letters to Mendel, students should describe the structure of a typical eukaryotic gene, the structure of DNA, and how genes are parts of chromosomes.

31. Sample answer: Two strands with paired bases held together by weak hydrogen bonds can be easily pulled apart. New bases lined up on the two strands by base-pairing rules would generate two molecules with the same base sequence.

Use Science Graphics

A scientist studied the effect of exposing DNA to various wavelengths of ultraviolet light. The scientist determined the number of copying errors made after exposure to ultraviolet rays. The graph shows the results. Use the graph to answer questions 27 and 28.

27. Interpret Graphs. The most damaging effects of ultraviolet light on DNA replication occur at which wavelength?

28. Infer. What conclusion would you draw from the graph about the effect of ultraviolet light on living organisms?

Pose Questions

Ozone is a molecule that is very effective at absorbing ultraviolet light from the sun. Evidence indicates that human activities have contributed to the destruction of ozone in the atmosphere. What question would you ask about the effect of removing ozone from the atmosphere?

Write About Science

30. Explanation. Recall that Gregor Mendel concluded that factors, which we now call genes, determine the traits that pass from one generation to the next. Imagine that you could send a letter backward in time to Mendel. Write a letter to him in which you explain what a gene consists of in molecular terms.

31. Assess the Big idea. In their original paper describing the structure of DNA, Watson and Crick noted in a famous sentence that the structure they were proposing immediately suggested how DNA could make a copy of itself. Explain what Watson and Crick meant when they said this.

Analyzing Data

The following table shows the results of measuring the percentages of the four bases in the DNA of several different organisms. Some of the values are missing from the table.

<table>
<thead>
<tr>
<th>Organism</th>
<th>A</th>
<th>G</th>
<th>T</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>19.9</td>
<td>29.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chicken</td>
<td>28.8</td>
<td></td>
<td></td>
<td>21.5</td>
</tr>
<tr>
<td>Bacterium (S. lutea)</td>
<td>13.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

32. Predict. Based on Chargaff’s rule, the percentage of adenine bases in human DNA should be around

a. 30.9%.
b. 19.9%.
c. 21.5%.
d. 13.4%.

33. Calculate. The value for the percent of guanine bases in the bacterium would be expected to be about

a. 13.4%.
b. 28.8%.
c. 36.6%.
d. There is not enough information given.

34. Predict. If the two DNA strands of the bacterium were separated and the base composition of just one of the strands was determined, you could expect

a. the amount of A to equal the amount of T.
b. the amount of C to equal the amount of G.
c. the amount of A to equal the amounts of T, C, and G.
d. the four nitrogenous bases to have any value.
Compared to eukaryotic cells, prokaryotic cells contain
A about 1000 times more DNA.
B about one thousandth as much DNA.
C twice as much DNA.
D the same amount of DNA.

Questions 9–10
Under ideal conditions, a single bacterial cell can reproduce every 20 minutes. The graph shows how the total number of cells under ideal conditions can change over time.

9. How many cells are present after 80 minutes?
A 1
B 2
C 16
D 32

10. If the DNA of this bacterium is 4 million base pairs in length, how many total molecules of A, T, C, and G are required for replication to be successful?
A 2 million
B 4 million
C 8 million
D 32 million

Open-Ended Response
11. Describe how eukaryotic cells are able to keep such large amounts of DNA in the small volume of the cell nucleus.

Test-Taking Tip
USE SCRATCH PAPER
Tell students that when they are asked to find the solution to a problem, such as the complementary sequence of DNA, they should first solve the problem on scratch paper. They should then compare their answer with the options provided. This method will help them avoid answer choices that are very similar, but not identical to, the correct answer choice.
RNA and Protein Synthesis

Q: How does information flow from DNA to RNA to direct the synthesis of proteins?

Connect to the Big Idea

Have students look at the photograph and read the caption. Call on a volunteer to describe how the two tigers differ. (One has orange and black fur, and the other has white and brown fur.) Help students connect this observation with the Big Idea of Information and Heredity. Explain that genes carry the information needed by cells to produce proteins, and proteins determine traits such as fur color. Remind students that genes are contained within the nucleus. Add that proteins are made, or synthesized, in the cytoplasm. Then, have students anticipate the answer to the question, How does information flow from DNA to RNA to direct the synthesis of proteins?

Information and Heredity

Have students read over the Chapter Mystery. Remind them that DNA is the universal code for life and that it helps determine an organism’s characteristics. Stress the universality of the code to help students understand how a mouse gene inserted into a fruit fly could lead to a fruit fly with many eyes. Then, discuss with the class why scientists would want to transplant a mouse gene into a fruit fly. Challenge students to predict what scientists might learn by doing this.

Understanding by Design

Chapter 13 provides knowledge that is fundamental to the Unit 4 Enduring Understanding: DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics. As shown in the graphic organizer at the right, the chapter explains how information encoded in DNA flows from the nucleus to the cytoplasm, where it directs protein synthesis.

PERFORMANCE GOALS

Students will analyze data, interpret diagrams, and use analogies to develop an understanding of how the information in DNA is used to direct protein synthesis and influence an organism’s characteristics. At the end of the chapter, they will write a story about gene regulation and develop a research proposal about how RNA interference affects gene expression.
It was definitely not a science fiction movie. The animal in the laboratory was real. Besides having two forward-looking eyes, it also had eyes on its knees and eyes on its hind legs. It even had eyes in the back of its head! Yet as strange as it looked, this animal was not a monster. It was simply a fruit fly with eyes in very strange places. These eyes looked like the fly’s normal compound eyes, but a mouse gene transplanted into the fly’s DNA had produced them. How could a mouse gene produce extra eyes in a fly?

As you read this chapter, look for clues to explain how a gene that normally controls the growth of eyes in mice could possibly cause a fly to grow extra eyes in unusual places. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the mouse-eyed fly is only the beginning. Take a video field trip with the eecgeeks of Untamed Science to see where this mystery leads.

What’s Online

Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
Students can investigate how genes transplanted from a mouse are able to control the development of extra eyes in a fruit fly.

UNTAMED SCIENCE VIDEO
To further explore how mutations affect species, students can take a video field trip with Untamed Science.

VISUAL ANALOGY
Using master plans and blueprints as an analogy for DNA and RNA helps students comprehend the different roles of these two types of molecules.

INTERACTIVE ART
This animation of transcription and translation helps students make sense of the processes involved in protein synthesis.

ART IN MOTION
Students will have a better understanding of RNA editing by watching an animation that shows how it happens.

TUTOR TUBE
Students will hear about the importance of proteins in determining phenotype.

ART REVIEW
This drag-and-drop activity gives students a chance to review different types of mutations.

DATA ANALYSIS
Students can analyze and interpret data on mutations in the lac operon of E. coli.
The Role of RNA

How does RNA differ from DNA?

When Watson and Crick solved the double-helix structure of DNA, they understood right away how DNA could be copied. All a cell had to do was to separate the two strands and then use base pairing to make a new complementary strand for each. But the structure of DNA by itself did not explain how a gene actually works. That question required a great deal more research. The answer came from the discovery that another nucleic acid—ribonucleic acid, or RNA—was involved in putting the genetic code into action.

RNA, like DNA, is a nucleic acid that consists of a long chain of nucleotides. In a general way, genes contain coded DNA instructions that tell cells how to build proteins. The first step in decoding these genetic instructions is to copy part of the base sequence from DNA into RNA. RNA then uses these instructions to direct the production of proteins, which help to determine an organism's characteristics.

Comparing RNA and DNA

Remember that each nucleotide in DNA is made up of a 5-carbon sugar, a phosphate group, and a nitrogenous base. This is true for RNA as well. But there are three important differences between RNA and DNA: (1) the sugar in RNA is ribose instead of deoxyribose, (2) RNA is generally single-stranded and not double-stranded, and (3) RNA contains uracil in place of thymine. These chemical differences make it easy for enzymes in the cell to tell DNA and RNA apart.

You can compare the different roles played by DNA and RNA molecules in directing the production of proteins to the two type of plans builders use. A master plan has all the information needed to construct a building. But builders never bring a valuable master plan to the job site, where it might be damaged or lost. Instead, as Figure 13–1 shows, they work from blueprints, inexpensive, disposable copies of the master plan.

THINK ABOUT IT

We know that DNA is the genetic material, and we know that the sequence of nucleotide bases in its strands must carry some sort of code. For that code to work, the cell must be able to understand it. What exactly do those bases code for? Where is the cell's decoding system?
Similarly, the cell uses the vital DNA “master plan” to prepare RNA “blueprints.” The DNA molecule stays safely in the cell’s nucleus, while RNA molecules go to the protein-building sites in the cytoplasm—the ribosomes.

**Functions of RNA** You can think of an RNA molecule as a disposable copy of a segment of DNA, a working facsimile of a single gene. RNA has many functions, but most RNA molecules are involved in just one job—protein synthesis. RNA controls the assembly of amino acids into proteins. Like workers in a factory, each type of RNA molecule specializes in a different aspect of this job. Figure 13–2 shows the three main types of RNA: messenger RNA, ribosomal RNA, and transfer RNA.

- **Messenger RNA** Most genes contain instructions for assembling amino acids into proteins. The RNA molecules that carry copies of these instructions are known as messenger RNA (mRNA). They carry information from DNA to other parts of the cell.
- **Ribosomal RNA** Proteins are assembled on ribosomes, small organelles composed of two subunits. These subunits are made up of several ribosomal RNA (rRNA) molecules and as many as 80 different proteins.
- **Transfer RNA** When a protein is built, a third type of RNA molecule transfers each amino acid to the ribosome as it is specified by the coded messages in mRNA. These molecules are known as transfer RNA (tRNA).

**Address Misconceptions**

**Importance of RNA** Students often fail to appreciate the importance of other genetic material besides DNA. Make sure they are aware that DNA is the inherited genetic material but RNA is the genetic material that carries out the instructions encoded in DNA. Without RNA, the instructions in DNA could not be used by cells.

In addition to the three types of RNA described above, a fourth type of RNA is also at work in cells. This type of RNA, called small nuclear RNA (snRNA) is involved in the important role of editing mRNA before it leaves the nucleus. snRNA is only found in the nucleus in combination with certain proteins, called small ribonucleoproteins, or snRNP (snurps). Snurp-snRNA complexes are given the name spliceosomes. They have a role that is somewhat analogous to ribosomes in the cytoplasm. As ribosomes join together amino acids to form chains of polypeptides, spliceosomes splice together exons to form edited strands of mRNA.
RNA Synthesis

How does the cell make RNA?

Cells invest large amounts of raw material and energy into making RNA molecules. Understanding how cells do this is essential to understanding how genes work.

Transcription

Most of the work of making RNA takes place during **transcription**. In transcription, segments of DNA serve as templates to produce complementary RNA molecules. The base sequences of the transcribed RNA complement the base sequences of the template DNA.

In prokaryotes, RNA synthesis and protein synthesis take place in the cytoplasm. In eukaryotes, RNA is produced in the cell's nucleus and then moves to the cytoplasm to play a role in the production of protein. Our focus here is on transcription in eukaryotic cells.

Transcription requires an enzyme, known as **RNA polymerase**, that is similar to DNA polymerase. RNA polymerase binds to DNA during transcription and separates the DNA strands. It then uses one strand of DNA as a template from which to assemble nucleotides into a complementary strand of RNA, as shown in Figure 13–3. The ability to copy a single DNA sequence into RNA makes it possible for a single gene to produce hundreds or even thousands of RNA molecules.

**FIGURE 13–3** Transcribing DNA into RNA

During transcription, the enzyme RNA polymerase uses one strand of DNA as a template to assemble complementary nucleotides into a strand of RNA.

**DIFFERENTIATED INSTRUCTION**

**LPR** Less Proficient Readers Some students may be confused by the multiple steps of RNA synthesis. Suggest that they make a Flowchart showing the sequence of steps in the process. Their flowchart should include the steps of both DNA transcription and RNA editing. Encourage them to add simple sketches to the steps of their flowchart.


**Focus on ELL: Extend Language**

BEGINNING AND INTERMEDIATE SPEAKERS Have students divide a sheet of paper into four equal parts. In the upper left square, have them write the word transcription. In the upper right square, ask them to sketch the transcription process, using Figure 13–3 as a guide. In the lower left square, ask them to write a definition of transcription, in their own words, based on the diagram. Then, tell them to write an original sentence about transcription in the lower right square. Give students a chance to share their work with other students.

**UbD** Check for Understanding

**VISUAL REPRESENTATION**

Ask students to make a **Concept Map** about RNA, with the term RNA in the center of the map. The concept map should include information about the general structure of RNA and the specific functions of the three main types of RNA.


**ADJUST INSTRUCTION**

If students struggle to complete their concept maps, have them exchange their maps with a partner. Have partners discuss the concepts and relationships represented in the maps and revise them as necessary.

In InterActive Art: Transcription and Translation, students can explore transcription with an interactive version of Figure 13–3. This activity also covers translation, which students will learn in Lesson 13.2.
**Promoters** How does RNA polymerase know where to start and stop making a strand of RNA? The answer is that RNA polymerase doesn’t bind to DNA just anywhere. The enzyme binds only to **promoters**, regions of DNA that have specific base sequences. Promoters are signals in the DNA molecule that show RNA polymerase exactly where to begin making RNA. Similar signals in DNA cause transcription to stop when a new RNA molecule is completed.

**RNA Editing** Like a writer’s first draft, RNA molecules sometimes require a bit of editing before they are ready to be read. These pre-mRNA molecules have bits and pieces cut out of them before they can go into action. The portions that are cut out and discarded are called **introns**, in eukaryotes, introns are taken out of pre-mRNA molecules while they are still in the nucleus. The remaining pieces, known as **exons**, are then spliced back together to form the final mRNA, as shown in Figure 13–4.

Why do cells use energy to make a large RNA molecule and then throw parts of that molecule away? That’s a good question, and biologists still don’t have a complete answer. Some pre-mRNA molecules may be cut and spliced in different ways in different tissues, making it possible for a single gene to produce several different forms of RNA. Introns and exons may also play a role in evolution, making it possible for very small changes in DNA sequences to have dramatic effects on how genes affect cellular function.

**Assessment Answers**

1a. RNA contains the sugar ribose instead of deoxyribose, is generally single-stranded rather than double-stranded, and contains uracil instead of thymine.

1b. Messenger RNA carries instructions for polypeptide synthesis from DNA in the nucleus to ribosomes in the cytoplasm. Ribosomal RNA forms an important part of both subunits of a ribosome, where proteins are assembled. Transfer RNA carries amino acids to a ribosome and matches them to the coded mRNA message.

1c. Sample answer: Proteins must be continuously synthesized in the cell, so the instructions coded in genes must be used over and over again. Therefore, a single gene must be able to produce hundreds or thousands of the same RNA molecules for protein synthesis.

2a. During transcription, the enzyme RNA polymerase binds to DNA and separates the DNA strands. It then uses one strand of DNA as a template to assemble nucleotides into a complementary strand of RNA.

2b. Sample answer: If introns were not removed, the instructions carried by mRNA for assembling amino acids into a protein might be incorrect, and the resulting protein might not function properly.

3. Answers will vary but should show that students understand the different functions of mRNA, rRNA, and tRNA in protein synthesis.
Getting Started

Objectives

13.2.1 Identify the genetic code and explain how it is read.
13.2.2 Summarize the process of translation.
13.2.3 Describe the “central dogma” of molecular biology.

Student Resources

Study Workbooks A and B, 13.2 Worksheets
Spanish Study Workbook, 13.2 Worksheets

Build Background

Introduce the genetic code by giving the class an encoded message to translate. On the board, write:

9  3-1-14  18-5-1-4  20-8-9-19  3-15-4-5

Tell students that each number represents a letter (a = 1, b = 2, c = 3, and so on). After students have deciphered the message (I can read this code), explain that RNA also contains a code.

Answers

FIGURE 13–5 AUG, AAC, and UCU

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES
II, V

CONTENT
B.2, B.3, C.1.c, C.2.a, G.3

INQUIRY
A.1.b, A.2.a

THINK ABOUT IT

How would you build a system to read the messages that are coded in genes and transcribed into RNA? Would you read the bases one at a time, as if the code were a language with just four words—one word per base? Perhaps you would read them, as we do in English, as individual letters that can be combined to spell longer words.

The Genetic Code

What is the genetic code, and how is it read?

The first step in decoding genetic messages is to transcribe a nucleotide base sequence from DNA to RNA. This transcribed information contains a code for making proteins. You learned in Chapter 2 that proteins are made by joining amino acids together into long chains, called polypeptides. As many as 20 different amino acids are commonly found in polypeptides.

The specific amino acids in a polypeptide, and the order in which they are joined, determine the properties of different proteins. The sequence of amino acids influences the shape of the protein, which in turn determines its function. How is the order of bases in DNA and RNA molecules translated into a particular order of amino acids in a polypeptide?

As you know from Lesson 13.1, RNA contains four different bases: adenine, cytosine, guanine, and uracil. In effect, these bases form a “language” with just four “letters”: A, C, G, and U. We call this language the genetic code. How can a code with just four letters carry instructions for 20 different amino acids? The genetic code is read three “letters” at a time, so that each “word” is three bases long and corresponds to a single amino acid. Each three-letter “word” in mRNA is known as a codon. As shown in Figure 13–5, a codon consists of three consecutive bases that specify a single amino acid to be added to the polypeptide chain.

FIGURE 13–5 Codons A codon is a group of three nucleotide bases in messenger RNA that specifies a particular amino acid. Observe What are the three-letter groups of the codons shown here?

AUG AAC CUC
How to Read Codons  Because there are four different bases in RNA, there are 64 possible three-base codons (4 × 4 × 4 = 64) in the genetic code. Figure 13–6 shows these possible combinations. Most amino acids can be specified by more than one codon. For example, six different codons—UUA, UUG, CUU, CUC, CUA, and CUG—specify leucine. But only one codon—UGG—specifies the amino acid tryptophan.

Decoding codons is a task made simple by use of a genetic code table. Just start at the middle of the circle with the first letter of the codon, and move outward. Next, move out to the second ring to find the second letter of the codon. Find the third and final letter among the smallest set of letters in the third ring. Then read the amino acid in that sector.

Start and Stop Codons  Any message, whether in a written language or the genetic code, needs punctuation marks. In English, punctuation tells us where to pause, when to sound excited, and where to start and stop a sentence. The genetic code has punctuation marks, too. The methionine codon AUG, for example, also serves as the initiation, or “start,” codon for protein synthesis. Following the start codon, mRNA is read, three bases at a time, until it reaches one of three different “stop” codons, which end translation. At that point, the polypeptide is complete.

**FIGURE 13–6 Reading Codons**

This circular table shows the amino acid to which each of the 64 codons corresponds. To read a codon, start at the middle of the circle and move outward.

1. To decode the codon CAC, find the first letter in the set of bases at the center of the circle.
2. Find the second letter of the codon, A, in the “C” quarter of the next ring.
3. Find the third letter, C, in the next ring, in the “C,A” grouping.
4. Read the name of the amino acid in that sector—in this case histidine.

### How Does a Cell Interpret Codons?

1. A certain gene has the following base sequence:
   
   GACAAGTCACAAATC

   Write this sequence on a separate sheet of paper.

2. From left to right, write the sequence of the mRNA molecule transcribed from this gene.

3. Using Figure 13–6, read the mRNA codons from left to right. Then write the amino acid sequence of the polypeptide.

**ANALYZE AND CONCLUDE**

1. The polypeptide produced in step 3 is leucine-phenylalanine-arginine-cysteine-stop. In step 4, the polypeptide produced is aspartic acid-cysteine-glycine-leucine-valine. They are different because the codons are read in the opposite direction.

2. Sample answer: Cells usually decode nucleotides in one direction only. Otherwise, the nucleotides could be reversed and code for a different sequence of amino acids.

### Teach

#### Use Visuals

Explain how to use Figure 13–6 to identify the amino acid that corresponds to a particular codon. Then, write several codons on the board, and call on students to name the amino acid each one represents. Reverse the process by writing the names of several amino acids and having students identify the codons that represent them. Finally, guide students in drawing conclusions about the genetic code.

**Ask** How many amino acids does each codon represent? (one)

**Ask** How many codons can code for a single amino acid? (from one to six)

**Ask** What else may codons represent? (stop and start)

Point out that the methionine codon, AUG, also means “start.” Call on a volunteer to explain how the stop and start codons are interpreted during protein synthesis.

#### DIFFERENTIATED INSTRUCTION

**Special Needs** Some students may find it difficult to understand and use Figure 13–6. Pair these students with students who have a good understanding of the material, and have partners work together to make index cards to represent the genetic code. Tell them to write the name of an amino acid on the front of each card and to list all of its corresponding codons on the back of the card. Let students use the index cards instead of Figure 13–6 when they answer questions about the genetic code.

**Struggling Students** Help students access genetic code content by presenting and discussing a visual representation of the code that differs from the diagram in Figure 13–6. For example, show students a rectangular matrix of the code. Have them take notes on the discussion and then use the notes to explain the alternative code representation to another student.
As students examine Figure 13–7, ask volunteers to briefly describe transcription and the structure and function of ribosomes. Describe how a ribosome moves along an mRNA strand, like a bead sliding along a string, translating the strand of mRNA as it moves.

**Ask** What role does transfer RNA play in translation? *(It brings amino acids to the ribosome.)*

**Ask** If an mRNA codon has the bases CUA, what bases will the corresponding transfer RNA anticodon have? *(GAU)*

**DIFFERENTIATED INSTRUCTION**

**ELL** English Language Learners Instruct students to complete an ELL Frayer Model for the term *translation*. Tell them to define the term and to sketch the translation process, using Figure 13–7 as a guide. For their example, they can write a sequence of codons and their matching anticodons and amino acids. Then, have students write a definition of the term *translation* into their own language, if possible.

**Study Wkbks A/B, Appendix S26, ELL Frayer Model. Transparencies, GO10.**

**LPR** Less Proficient Readers Use Cloze Prompts to help students focus on the most important points as they read about translation in the text. Copy important sentences from the passage, leaving a term out of each one. Then, have students fill in the blanks as they read.

**Study Wkbks A/B, Appendix S2, Cloze Prompts.**

*In InterActive Art: Transcription and Translation, students can explore translation with an interactive version of Figure 13–7. To help students understand how the products of translation—proteins—relate to phenotype, have them view Tutor Tube: Why Are Proteins So Important?*

**Address Misconceptions**

**Products of Translation** Students frequently misidentify the products of translation as mRNA or amino acids. Stress that mRNA is the product of transcription, not translation, and that amino acids are already available in the cell—they just need to be joined together in the correct sequence to make a polypeptide.

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**Translation**

What role does the ribosome play in assembling proteins?

The sequence of nucleotide bases in an mRNA molecule is a set of instructions that gives the order in which amino acids should be joined to produce a polypeptide. Once the polypeptide is complete, it then folds into its final shape or joins with other polypeptides to become a functional protein.

If you've ever tried to assemble a complex toy, you know that instructions alone don't do the job. You need to read them and then put the parts together. In the cell, a tiny factory—the ribosome—carries out both these tasks. Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains. The decoding of an mRNA message into a protein is a process known as translation.

**Steps in Translation** Transcription isn't part of the translation process, but it is critical to it. Transcribed mRNA directs that process. In a eukaryotic cell, transcription goes on in the cell's nucleus; translation is carried out by ribosomes after the transcribed mRNA enters the cell's cytoplasm. Refer to Figure 13–7 as you read about translation.

Translation begins when a ribosome attaches to an mRNA molecule in the cytoplasm. As each codon passes through the ribosome, tRNAs bring the proper amino acids into the ribosome. One at a time, the ribosome then attaches these amino acids to the growing chain.

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**Check for Understanding**

**ORAL QUESTIONING** Call on students to answer the following questions about the genetic code and translation:

- How is a codon similar to a word? How is it different from a word?
- What are general characteristics of the genetic code?
- Describe the process of translation.

**ADJUST INSTRUCTION**

Discuss any questions that students answer incorrectly or incompletely. Then, ask if anyone still has questions. Call on volunteers to address any additional questions that students raise.
Each tRNA molecule carries just one kind of amino acid. In addition, each tRNA molecule has three unpaired bases, collectively called the **anticodon.** Each tRNA anticodon is complementary to one mRNA codon.

In the case of the tRNA molecule for methionine, the anticodon is UAC, which pairs with the methionine codon, AUG. The ribosome has a second binding site for a tRNA molecule for the next codon. If that next codon is UUC, a tRNA molecule with an AAG anticodon fits against the mRNA molecule held in the ribosome. That second tRNA molecule brings the amino acid phenylalanine into the ribosome. 

Like an assembly-line worker who attaches one part to another, the ribosome helps form a peptide bond between the first and second amino acids—methionine and phenylalanine. At the same time, the bond holding the first tRNA molecule to its amino acid is broken. That tRNA then moves into a third binding site, from which it exits the ribosome. The ribosome then moves to the third codon, where tRNA brings it the amino acid specified by the third codon. 

The polypeptide chain continues to grow until the ribosome reaches a “stop” codon on the mRNA molecule. When the ribosome reaches a stop codon, it releases both the newly formed polypeptide and the mRNA molecule, completing the process of translation.

### Use Models

Ask groups of students to use materials of their choice to make a three-dimensional model representing the process of translation. Suitable materials might include modeling clay, craft sticks, various beads, dried pasta in different shapes and colors, chenille stems, string, or yarn. Remind students to include in their model a strand of mRNA, a ribosome, a few molecules of tRNA, and a short polypeptide. Give groups a chance to share their models with the class.

### DIFFERENTIATED INSTRUCTION

#### L1 Special Needs  
Support special needs students by modeling the processes of transcription and translation as a class. Sit at your desk, and tell the class that you represent DNA in the nucleus of a cell and the classroom represents the cytoplasm of the cell. Assign a student to represent a ribosome, and place a handful of multicolored paper clip “amino acids” next to him or her. On a piece of paper, write the message, “Clip a yellow and white paper clip together.” Ask another student to come to your desk, copy the message on a scrap of paper, and carry the copy to the “ribosome.” After the “ribosome” student follows the instructions in the note, explain how the exercise models the way information encoded in DNA is carried from the nucleus to the cytoplasm and acted upon at a ribosome. Ask students if they know what the messenger student represents. (mRNA)

#### LPR Less Proficient Readers  
Use a more familiar meaning of the term translation as an analogy to help students understand the process of mRNA translation. On the board, write specific examples showing how words of one language can be translated into another language (e.g., mother to madre, street to rue). Ask English language learners or students who have studied a foreign language to translate a few words, as well. Then, explain that translation in genetics is a similar process. The codons of mRNA are like words of one language, and they are translated into amino acids, which are like words of another language.

### Answers

**IN YOUR NOTEBOOK** The ribosome positions the start codon of mRNA to attract its anticodon, which is part of a tRNA molecule. The ribosome also binds the next codon and attracts its anticodon. Then, the ribosome joins the first two amino acids and breaks the bond between the first amino acid and its tRNA. The ribosome moves along the mRNA strand, repeating this process until the ribosome reaches a stop codon. Then, it releases the newly formed polypeptide and the mRNA strand.
LESSON 13.2

Lead a Discussion
Write the following on the board:

DNA → RNA → Protein

Tell students this represents the central dogma of molecular biology. Call on several volunteers to express the central dogma in their own words. Then, lead a discussion about its implications and limitations.

Ask What does the central dogma imply about the role of RNA? 
(Sample answer: It’s the step between DNA and proteins.)

Point out that the central dogma does have limitations. For example, it doesn’t represent the other roles of RNA. Explain that many RNA molecules are not translated into proteins but still play important roles in gene expression. Tell students that other roles of RNA are discussed in Lesson 13.4.

DIFFERENTIATED INSTRUCTION

ELL Advanced Students Ask several students to choose sides and debate the issue of whether the central dogma of molecular biology is still useful despite its limitations. Give them a chance to find documentation to support their side of the issue and then to present their debate in class.

ELL Focus on ELL: Access Content

ALL SPEAKERS Have students review lesson concepts by participating in a Core Concept Discussion. Ask each student to write down one core concept from the lesson. Accept words or short phrases from beginning speakers. Then, have students form small groups that contain a mix of students with differing English proficiency. Group members should take turns discussing one another’s core concepts. Discuss a few of the more difficult concepts as a class.

Study Wkbks A/B, Appendix S3, Core Concept Discussion.

Students are likely to explain that a mouse’s gene works inside the cells of a fly because the genetic code is nearly universal. In almost all organisms, the same amino acids are assigned to particular codons, and the code is always read three bases at a time and in the same direction. Students can go online to Biology.com to gather their evidence.

The Roles of tRNA and rRNA in Translation All three major forms of RNA—mRNA, tRNA, and rRNA—come together in the ribosome during translation. The mRNA molecule, of course, carries the coded message that directs the process. The tRNA molecules deliver exactly the right amino acid called for by each codon on the mRNA. The tRNA molecules are, in effect, adapters that enable the ribosome to “read” the mRNA’s message accurately and to get the translation just right.

Ribosomes themselves are composed of roughly 80 proteins and three or four different rRNA molecules. These rRNA molecules help hold ribosomal proteins in place and help locate the beginning of the mRNA message. They may even carry out the chemical reaction that joins amino acids together.

The Molecular Basis of Heredity

What is the “central dogma” of molecular biology?

Gregor Mendel might have been surprised to learn that most genes contain nothing more than instructions for assembling proteins. He might have asked what proteins could possibly have to do with the color of a flower, the shape of a leaf, or the sex of a newborn baby. The answer is that proteins have everything to do with these traits. Remember that many proteins are enzymes, which catalyze and regulate chemical reactions. A gene that codes for an enzyme to produce pigment can control the color of a flower. Another gene produces proteins that regulate patterns of tissue growth in a leaf. Yet another may trigger the female or male pattern of development in an embryo.

As you’ve seen, once scientists learned that genes were made of DNA, a series of other discoveries soon followed. Before long, with the genetic code in hand, a new scientific field called molecular biology had been established. Molecular biology seeks to explain living organisms by studying them at the molecular level, using molecules like DNA and RNA. One of the earliest findings came to be known, almost jokingly, as the field’s “central dogma.”

The central dogma of molecular biology is that information is transferred from DNA to RNA to protein. In reality, there are many exceptions to this “dogma,” including viruses that transfer information in the opposite direction, from RNA to DNA. Nonetheless, it serves as a useful generalization that helps to explain how genes work. Figure 13–9 illustrates gene expression, the way in which DNA, RNA, and proteins are involved in putting genetic information into action in living cells.

One of the most interesting discoveries of molecular biology is the near-universal nature of the genetic code. Although some organisms show slight variations in the amino acids assigned to particular codons, the code is always read three bases at a time and in the same direction. Despite their enormous diversity in form and function, living organisms display remarkable unity at life’s most basic level, the molecular biology of the gene.

How Science Works

CHALLENGES TO THE CENTRAL DOGMA

The central dogma of molecular biology was first postulated by Francis Crick in 1958. Over most of the next 50 years, it was the cornerstone of the field, focusing research on DNA segments that code for proteins. However, research shows that the central dogma is too simple and may be pointing research in the wrong direction. It now seems that RNA may play at least as important a role in genetics and evolution as DNA. For example, researchers have found that a single RNA molecule is probably responsible for many of the differences between human and chimpanzee brains.

Other researchers, studying the human genome, have shown that so-called junk DNA that doesn’t code for proteins may actually be transcribed into RNA and play important roles in cells, although most of these roles are still unknown.
1a. The genetic code is read one codon, or three bases at a time; each codon, except the stop codon, codes for an amino acid.

1b. Codons are three-letter “words” in mRNA that specify amino acids. Anticodons are three unpaired bases in tRNA, complementary to mRNA codons.

1c. Tryptophan, lysine, cysteine

2a. During translation, a ribosome uses the sequence of codons in mRNA to assemble amino acids into a polypeptide chain. The correct amino acids are brought to the ribosome by tRNA.

2b. Check that students’ responses identify differences between protein synthesis and DNA replication.

3a. In all organisms the code is read three bases at a time and in the same direction. In most organisms the same amino acids are assigned to particular codons.

3b. It refers to the way in which DNA, RNA, and proteins are involved in putting genetic information into action in living cells.

4. Questions should pertain to a single component or step in translation, and one of the questions should be restated as a testable hypothesis. Sample answer: Question: What happens to mRNA after it has been translated by a ribosome? Hypothesis: After mRNA has been translated, it is released from the ribosome.
What are mutations?
Now and then cells make mistakes in copying their own DNA, inserting the wrong base or even skipping a base as a strand is put together. These variations are called mutations, from the Latin word *mutare*, meaning "to change.

Mutations are heritable changes in genetic information. Mutations come in many different forms. Figure 13–10 shows two of the countless examples. But all mutations fall into two basic categories: Those that produce changes in a single gene are known as gene mutations. Those that produce changes in whole chromosomes are known as chromosomal mutations.

**Types of Mutations**

**What are mutations?**
Now and then cells make mistakes in copying their own DNA, inserting the wrong base or even skipping a base as a strand is put together. These variations are called mutations, from the Latin word *mutare*, meaning "to change.

**Mutations are heritable changes in genetic information.**

Mutations come in many different forms. Figure 13–10 shows two of the countless examples. But all mutations fall into two basic categories: Those that produce changes in a single gene are known as gene mutations. Those that produce changes in whole chromosomes are known as chromosomal mutations.

**THINK ABOUT IT**
The sequence of bases in DNA are like the letters of a coded message, as we’ve just seen. But what would happen if a few of those letters changed accidentally, altering the message? Could the cell still understand its meaning? Think about what might happen if someone changed at random a few lines of code in a computer program that you rely on. Knowing what you already do about the genetic code, what effects would you predict such changes to have on genes and the polypeptides for which they code?

**Vocabulary**
- mutation
- point mutation
- frameshift mutation
- mutagen
- polyploidy

**Taking Notes**
**Preview Visuals**
Before you read, look at Figures 13–11 and 13–12. As you read, note the changes produced by various gene and chromosomal mutations.

**Figure 13–10 Plant and Animal Mutations**

- The elongated shape of this flower is caused by a mutation that affects the growing regions of the flower tissue.
- A mutation in the gene known as bithorax has produced an extra set of wings in this fruit fly. (SEM: 20x/H11003)

**Teach for Understanding**

**ENDURING UNDERSTANDING** DNA is the universal code of life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

**GUIDING QUESTION** What happens when a cell’s DNA changes?

**EVIDENCE OF UNDERSTANDING** After completing the lesson, assign students the following assessment to show they understand mutations. Have students write one paragraph each on the types, causes, and effects of mutations. Tell them to assume their paragraphs will be read by middle-school students who have no prior knowledge of biology.
Gene Mutations Gene mutations that involve changes in one or a few nucleotides are known as point mutations because they occur at a single point in the DNA sequence. Point mutations include substitutions, insertions, and deletions. They generally occur during replication. If a gene in one cell is altered, the alteration can be passed on to every cell that develops from the original one. Refer to Figure 13–11 as you read about the different forms of point mutations.

In a substitution, one base is changed to a different base. Substitutions usually affect no more than a single amino acid, and sometimes they have no effect at all. For example, if a mutation changed one codon of mRNA from CCC to CCA, the codon would still specify the amino acid proline. But a change in the first base of the codon—changing CCC to ACC—would replace proline with the amino acid threonine.

Insertions and deletions are point mutations in which one base is inserted or removed from the DNA sequence. The effects of these changes can be dramatic. Remember that the genetic code is read three bases at a time. If a nucleotide is added or deleted, the bases are still read in groups of three, but now those groupings shift in every codon that follows the mutation.

Insertions and deletions are also called frameshift mutations because they shift the “reading frame” of the genetic message. By shifting the reading frame, frameshift mutations can change every amino acid that follows the point of the mutation. They can alter a protein so much that it is unable to perform its normal functions.

**In Your Notebook** Use a cause/effect diagram to describe the different types of gene mutations.

![Figure 13–11 Point Mutations](image)

**FIGURE 13–11 Point Mutations** These diagrams show how changes in a single nucleotide can affect the amino acid sequence of proteins. Analyze Data Which type of mutations affects only one amino acid in a protein? Which can affect more than one?

Quick Facts

**TIMING AND FREQUENCY OF MUTATIONS**

Mutations may occur at different times in the life cycle of an individual. Mutations that occur in gametes or just after fertilization affect all the cells of the organism. Mutations that occur during the embryonic stage, when cells and tissues are differentiating, cause mosaicism, in which only some cells of the organism have the mutation. Mutations that occur after an organism is fully formed affect only the cells in which they occur and their daughter cells. If these mutations occur in sex cells, they may be inherited by the organism’s offspring. On the contrary, if mutations occur in somatic (body) cells, the mutations will leave the gene pool when the organism dies. At the population level, some mutations are fairly common. They are called polymorphisms if they have allele frequencies greater than 1 percent. Polymorphisms contribute to normal human genetic variation.

**Use Visuals**

Teach

**Use Visuals**

Call on students to explain in their own words how the different types of gene mutations occur, based on the examples shown in Figure 13–11. Then, have students create their own examples of the three types of gene mutations.

**DIFFERENTIATED INSTRUCTION**

**ELL Struggling Students** On the board, write the following sentence:

The boysaw the tangent dog run.

Tell students to read the sentence, three letters at a time. Then, insert the letter x after the first The, and give students the same instruction. Repeat, but this time, delete the letter e in The. Explain how inserting or deleting a letter is like a frameshift mutation.

**ELL Focus on ELL: Build Background**

**BEGINNING AND INTERMEDIATE SPEAKERS** Ask students to write the term mutation on a Vocabulary Word Map. Then, familiarize them with mutations by showing visuals of organisms with and without visible traits caused by mutations. Discuss how changes in a cell’s DNA can produce these visible differences. Then, have them complete the map using the information on the page.

**Study Wkbks A/B, Appendix S32, Vocabulary Word Map. Transparencies, GO17.**

**Answers**

**FIGURE 13–11** Substitutions affect only one amino acid; insertions and deletions affect more than one nucleotide.

**IN YOUR NOTEBOOK** Students’ cause/effect diagrams may vary but should show they understand different types of gene mutations.
Expand Vocabulary

On the board, write the verbs delete, duplicate, and invert. Call on students to define each verb. (Sample answers: Delete means “to erase,” duplicate means “to copy,” and invert means “to reverse.”) Have students look at the deletion, duplication, and inversion mutation examples shown in Figure 13–12. Call on volunteers to explain how the meanings of the verbs relate to the manner in which the mutations occur. Then, write the term translocation on the board, and divide it into its parts. Ask students if they know what the parts mean. (Trans- means “across,” and location means “place.”) Call on a volunteer to explain how the meaning of the term relates to what happens when a translocation mutation occurs.

DIFFERENTIATED INSTRUCTION

Special Needs Have students model chromosomal mutations with strips of paper representing segments of chromosomes. Give them six strips of paper of the same length. On five of the strips, ask them to write the sequence of letters A B C D E F. Tell them to glue one of these strips across the top of a sheet of paper. Then, have them cut the remaining labeled strips into sections and rearrange them to illustrate each of the chromosomal mutations shown in Figure 13–12. Tell them to use the blank strip to make any extra parts they need for the mutations. Have students glue the rearranged strips below the original strip and label the type of mutation each rearrangement represents.

Answers

FIGURE 13–12 An inversion mutation reverses the direction of part of one chromosome. A translocation mutation attaches part of one chromosome to another chromosome.

Chromosomal Mutations Chromosomal mutations involve changes in the number or structure of chromosomes. These mutations can change the location of genes on chromosomes and can even change the number of copies of some genes. Figure 13–12 shows four types of chromosomal mutations: deletion, duplication, inversion, and translocation. Deletion involves the loss of all or part of a chromosome; duplication produces an extra copy of all or part of a chromosome; and inversion reverses the direction of parts of a chromosome. Translocation occurs when part of one chromosome breaks off and attaches to another.

Effects of Mutations

How do mutations affect genes?

Genetic material can be altered by natural events or by artificial means. The resulting mutations may or may not affect an organism. And some mutations that affect individual organisms can also affect a species or even an entire ecosystem.

Many mutations are produced by errors in genetic processes. For example, some point mutations are caused by errors during DNA replication. The cellular machinery that replicates DNA inserts an incorrect base roughly once in every 10 million bases. But small changes in genes can gradually accumulate over time.

Modeling Mutations

Small mutations in DNA can cause huge changes in the proteins that are synthesized. Similarly, small changes in a word can dramatically alter its meaning. Look at the following sequence of words:

milk mile wile wise wisp wisp

Notice that each word differs from the previous word by just one letter and that none of the words is meaningless. Think of these changes as “point mutations” that affect word meaning.

Analyze and Conclude

1. Apply Concepts Start with the word gene, and change it letter by letter to make new words. Make sure each new word is an actual word but not a proper noun. Write at least four “point mutations” of the word gene.

2. Apply Concepts Show how you could use words to model a frameshift mutation. (Hint: You can use a sentence.)

3. Use Models Use the words in this sentence to model a substitution mutation.

Analyze and Conclude

1. Sample answer: gene → gone → tone → tune → tuna

2. Answers will vary but should show that students understand that a frameshift occurs when a base is inserted or deleted, which shifts the “reading frame.” For example, they could write a sentence and then delete or insert a single letter so that the reading frame shifts and the letters no longer spell out recognizable words.

3. Sample answer: Changing words to works models a substitution mutation.
Stressful environmental conditions may cause some bacteria to increase mutation rates. This can actually be helpful to the organism, since mutations may sometimes give such bacteria new traits, such as the ability to consume a new food source or to resist a poison in the environment.

**Mutagens** Some mutations arise from mutagens, chemical or physical agents in the environment. Chemical mutagens include certain pesticides, a few natural plant alkaloids, tobacco smoke, and environmental pollutants. Physical mutagens include some forms of electromagnetic radiation, such as X-rays and ultraviolet light. If these agents interact with DNA, they can produce mutations at high rates. Cells can sometimes repair the damage; but when they cannot, the DNA base sequence changes permanently. Some compounds interfere with base-pairing, increasing the error rate of DNA replication. Others weaken the DNA strand, causing breaks and inversions that produce chromosomal mutations.

**Harmful and Helpful Mutations** As you’ve already seen, some mutations don’t even change the amino acid specified by a codon, while others may alter a complete protein or even an entire chromosome. The effects of mutations on genes vary widely. Some have little or no effect; and some produce beneficial variations. Some negatively disrupt gene function. Many if not most mutations are neutral; they have little or no effect on the expression of genes or the function of the proteins for which they code. Whether a mutation is negative or beneficial depends on how its DNA changes relative to the organism’s situation. Mutations are often thought of as negative, since they can disrupt the normal function of genes. However, without mutations, organisms could not evolve, because mutations are the source of genetic variability in a species.

**Harmful Effects** Some of the most harmful mutations are those that dramatically change protein structure or gene activity. The defective proteins produced by these mutations can disrupt normal biological activities, and result in genetic disorders. Some cancers, for example, are the product of mutations that cause the uncontrolled growth of cells. Sickle cell disease is a disorder associated with changes in the shape of red blood cells. You can see its effects in Figure 13–13. It is caused by a point mutation in one of the polypeptides found in hemoglobin, the blood’s principal oxygen-carrying protein. Among the symptoms of the disease are anemia, severe pain, frequent infections, and stunted growth.

**Connect to Health**

Elaborate on sickle cell disease to illustrate how the effects of a mutation may depend on the environment. Explain that sickle cell disease occurs only in heterozygotes for the sickle cell allele. Heterozygotes—those who have one sickle cell allele and one normal allele—do not have sickle cell disease, but may notice harmful effects at high altitudes. Both homozygotes and heterozygotes are resistant to the parasite that causes malaria. In areas like tropical Africa, where malaria is endemic, heterozygotes are more fit than people who are homozygous for the normal allele. This explains why the sickle cell allele is fairly common in some populations (including African and African-American populations), and why people in these populations have a relatively high risk of inheriting two copies of the mutant gene. Tell students they will learn more about sickle cell disease in Chapter 14.

**DIFFERENTIATED INSTRUCTION**

**Less Proficient Readers** Suggest that students make a Cluster Diagram to organize the information about the effects of mutations. They should write Effects of Mutations in the center circle of the diagram. In the major surrounding circles they should write Neutral Effects, Harmful Effects, and Helpful Effects. Additional circles should be used to add information as students read the text.

**Study Wkbks A/B, Appendix S19, Cluster Diagram. Transparencies, GO2.**

**Mystery Clue** Because they have not yet read about homebox genes, students might assume that a major chromosomal mutation would be required to cause more eyes than normal to appear on a fly. Students can go online to Biology.com to gather their evidence.
LESSON 13.3

Assess and RemEDIATE

EVALUATE UNDERSTANDING

Give each student seven index cards. Tell students to write or draw an example of one type of gene or chromosomal mutation on the front of each card and its name on the back. Ask students to exchange cards with a partner and try to identify the types of mutations from the examples. Then, have students complete the 13.3 Assessment.

REMEDICATION SUGGESTION

ELL English Language Learners If students have trouble with Question 2b, explain that the term significance means “importance.” Then, suggest that students reread the paragraphs about harmful and helpful mutations. As they do, they should look for information on how mutations are important to organisms and species.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Answers

IN YOUR NOTEBOOK Check that students have listed five examples of mutations. Classify each as neutral, harmful, or helpful, and explain your reasoning.

Assessment Answers

1a. Gene mutations involve changes in one or a few nucleotides. Chromosomal mutations involve changes in the number or structure of chromosomes.

1b. A frameshift mutation is an insertion or deletion that shifts the “reading frame” of the genetic message. An example is the insertion of an extra U in AUGCUC to make AUGUCUC. Following AUG, the “reading frame” is shifted by one base.

1c. Sample answer: To identify a gene mutation, a biologist might compare DNA base sequences among members of the species. To identify a chromosomal mutation, the biologist might examine some karyotypes.

2a. Effects of mutations on genes can be harmful, beneficial, or they can have little or no effect at all.

2b. Mutations are a source of genetic variation for living things. Sometimes variation can help organisms adapt to different or changing environments. Mutations are also necessary for species to evolve.

3. Students’ tables should contain much of the following information: Gene mutations involve changes in one or a few nucleotides. They include substitutions, insertions, and deletions. Insertions and deletions are called frameshift mutations because they change the “reading frame” of the genetic message. Gene mutations may or may not have major effects on an organism. Chromosomal mutations involve changes in the number or structure of chromosomes. They include deletions, duplications, inversions, and translocations. They can change the location of genes on chromosomes, and even the number of copies of genes. Chromosomal mutations generally have major effects on an organism.

Beneficial Effects Some of the variation produced by mutations can be highly advantageous to an organism or species. Mutations often produce proteins with new or altered functions that can be useful to organisms in different or changing environments. For example, mutations have helped many insects resist chemical pesticides. And some have enabled microorganisms to adapt to new chemicals in the environment.

Over the past 20 years, mutations in the mosquito genome have made many African mosquitoes resistant to the chemical pesticides once used to control them. This may be bad news for humans, but it is highly beneficial to the insects themselves. Beneficial mutations occur in humans, too, including ones that increase bone strength and density, making fractures less likely, and mutations that increase resistance to HIV, the virus that causes AIDS.

Plant and animal breeders often make use of “good” mutations. For example, when a complete set of chromosomes fails to separate during meiosis, the gametes that result may produce triploid (3N) or tetraploid (4N) organisms. The condition in which an organism has extra sets of chromosomes is called polyploidy. Polyploid plants are often larger and stronger than diploid plants. Important crop plants—including bananas and the limes shown in Figure 13–14—have been produced this way. Polyploidy also occurs naturally in citrus plants, often through spontaneous mutations.

FIGURE 13–14 Polyploid Plants

The fruit of the Tahiti lime is seedless, a result of polyploidy. Changes to the ploidy number of citrus plants can affect the size and strength of the trees as well as the quality and seediness of their fruit.

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**Prokaryotic Gene Regulation**

**How are prokaryotic genes regulated?**

As it turns out, bacteria and other prokaryotes do not need to transcribe all of their genes at the same time. To conserve energy and resources, prokaryotes regulate their activities, using only those genes necessary for the cell to function. For example, it would be wasteful for a bacterium to produce enzymes that are needed to make a molecule that is readily available from its environment. By regulating gene expression, bacteria can respond to changes in their environment—the presence or absence of nutrients, for example. How? DNA-binding proteins in prokaryotes regulate genes by controlling transcription. Some of these regulatory proteins help switch genes on, while others turn genes off.

How does an organism know when to turn a gene on or off? One of the keys to gene transcription in bacteria is the organization of genes into operons. An operon is a group of genes that are regulated together. The genes in an operon usually have related functions. *E. coli*, shown in Figure 13–15, provides us with a clear example. The 4288 genes that code for proteins in *E. coli* include a cluster of 3 genes that must be turned on together before the bacterium can use the sugar lactose as a food. These three lactose genes in *E. coli* are called the *lac* operon.

**Vocabulary**

- operon
- operator
- RNA interference
- differentiation
- homeotic gene
- homeobox gene
- Hox gene

**Taking Notes**

Outline Before you read, use the headings in this lesson to make an outline. As you read, fill in the subtopics and smaller topics. Then add phrases or a sentence after each subtopic that provides key information.

**THINK ABOUT IT** Think of a library filled with how-to books. Would you ever need to use all of those books at the same time? Of course not. If you wanted to know how to fix a leaky faucet, you'd open a book about plumbing but would ignore the one on carpentry. Now picture a tiny bacterium like *E. coli*, which contains more than 4000 genes. Most of its genes code for proteins that do everything from building cell walls to breaking down food. Do you think *E. coli* uses all 4000-plus volumes in its genetic library at the same time?

**Figure 13–15**

Small Cell, Many Genes

The common bacterium *E. coli* has more than 4000 genes.

**Teach for Understanding**

**ENDURING UNDERSTANDING** DNA is the universal code of life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

**GUIDING QUESTION** How do cells regulate gene expression?

**EVIDENCE OF UNDERSTANDING** After completing the lesson, assign students the following assessment to show they understand how eukaryotic cells regulate gene expression. Ask students to use presentation software to create and present a series of slides showing how gene expression in eukaryotic cells is regulated by transcription factors and RNA interference. Their slides should include both text and visuals.
LESSON 13.4

Use Visuals

Guide students in using Figure 13–16 to learn about prokaryotic gene regulation. Ask them to locate and identify the function of each of the following elements in the figure: repressor, promoter, operator, lac genes, RNA polymerase, lactose, and mRNA. Make sure they know that each panel shows the same segment of DNA in an E. coli bacterium. Point out that lactose is absent in the second panel but present in the third panel.

Ask In the second panel, what happens because lactose is absent? (The repressor binds to the operator, preventing RNA polymerase from binding to the promoter.)

Ask In the third panel, what happens because lactose is present? (Lactose binds to the repressor, preventing RNA polymerase from binding to the promoter. This allows RNA polymerase to bind to the promoter.)

DIFFERENTIATED INSTRUCTION

LPA Less Proficient Readers Have students fill in a Flowchart to sequence the events that occur during the process of prokaryote gene regulation, using the lac operon as an example. They should add to the flowchart a brief description and sketch of each event in the process as they read about it in the text.

Study Wkbks A/B, Appendix S25, Flowchart.

In the Data Analysis: A Complicated Operon, students analyze results of growing bacteria with lac operon mutations to identify which genes contain the mutations.

Answers

FIGURE 13–16 Sample answer: Cold air causes a furnace to turn on. When the air is no longer cold, the warmer temperature causes the furnace to turn off. Lactose works in a similar way. The presence of lactose causes lac genes to turn on. When lactose is no longer present, the absence of lactose causes lac genes to turn off.

The Lac Operon Why must E. coli be able to switch the lac genes on and off? Lactose is a compound made up of two simple sugars, galactose and glucose. To use lactose for food, the bacterium must transport lactose across its cell membrane and then break the bond between glucose and galactose. These tasks are performed by proteins coded for by the genes of the lac operon. This means, of course, that if the bacterium grows in a medium where lactose is the only food source, it must transcribe these genes and produce these proteins. If grown on another food source, such as glucose, it would have no need for these proteins.

Remarkably, the bacterium almost seems to “know” when the products of these genes are needed. When lactose is not present, the lac genes are turned off by proteins that bind to DNA and block transcription.

Promoters and Operators On one side of the operon’s three genes are two regulatory regions. The first is a promoter (P), which is a site where RNA-polymerase can bind to begin transcription. The other region is called the operator (O). The O site is where a DNA-binding protein known as the lac repressor can bind to DNA.

The Lac Repressor Blocks Transcription As Figure 13–16 shows, when the lac repressor binds to the O region, RNA polymerase cannot reach the lac genes to begin transcription. In effect, the binding of the repressor protein switches the operon “off” by preventing the transcription of its genes.

Lactose Turns the Operon “On” If the repressor protein is always present, how can the lac genes ever be switched on? Besides its DNA binding site, the lac repressor protein has a binding site for lactose itself. When lactose is added to the medium, it diffuses into the cell and attaches to the lac repressor. This changes the shape of the repressor protein in a way that causes it to fall off the operator. Now, with the repressor no longer bound to the O site, RNA polymerase can bind to the promoter and transcribe the genes of the operon. As a result, in the presence of lactose, the operon is automatically switched on.

FIGURE 13–16 Gene Expression in Prokaryotes

The lac genes in E. coli are turned off by lac repressors and turned on in the presence of lactose.

Use Analogies How is the way lactose turns genes on and off similar to the way cold air signals a furnace to turn on or off?

How Science Works

DISCOVERY OF THE LAC OPERON

The three French scientists who discovered the lac operon won the 1965 Nobel Prize in Physiology or Medicine for their work. Why was it considered such an important discovery? The lac operon is the first system of gene regulation ever discovered. It showed for the first time that structural genes, which code for proteins, are regulated by other genes. The existence of regulatory genes was unknown until then. The lac operon also provided a mechanism to explain how living cells could respond to environmental stimuli by controlling the expression of genes and thereby the enzymes and other proteins they code for.
Eukaryotic Gene Regulation

How are genes regulated in eukaryotic cells?

The general principles of gene regulation in prokaryotes also apply to eukaryotes, although there are differences. Most eukaryotic genes are controlled individually and have more complex regulatory sequences than those of the lac repressor system.

Figure 13–17 shows several features of a typical eukaryotic gene. One of the most interesting is the TATA box, a short region of DNA, about 25 or 30 base pairs before the start of a gene, containing the sequence TATATA or TATAAA. The TATA box binds a protein that helps position RNA polymerase by marking a point just before the beginning of a gene.

**Transcription Factors** Gene expression in eukaryotic cells can be regulated at a number of levels.

One of the most critical is the level of transcription, by means of DNA-binding proteins known as transcription factors. By binding DNA sequences in the regulatory regions of eukaryotic genes, transcription factors control the expression of those genes. Some transcription factors enhance transcription by opening up tightly packed chromatin. Others help attract RNA polymerase. Still others block access to certain genes, much like prokaryotic repressor proteins. In most cases, multiple transcription factors must bind before RNA polymerase is able to attach to the promoter region and start transcription.

Promoters have multiple binding sites for transcription factors, each of which can influence transcription. Certain factors activate scores of genes at once, dramatically changing patterns of gene expression in the cell. Other factors form only in response to chemical signals. Steroid hormones, for example, are chemical messengers that enter cells and bind to receptor proteins. These “receptor complexes” then act as transcription factors that bind to DNA, allowing a single chemical signal to activate multiple genes. Eukaryotic gene expression can also be regulated by many other factors, including the exit of mRNA molecules from the nucleus, the stability of mRNA, and even the breakdown of a gene’s protein products.

*In Your Notebook* Compare gene regulation in single-cell organisms and multicellular organisms.

**Check for Understanding**

**QUESTION BOX**

Establish an e-mail address for yourself. Give students the e-mail address and instruct them to send any questions they have about gene regulation. Suggest they check their understanding by trying to answer the two Key Questions about gene regulation first. If they are unsure of the answers, encourage them to identify specific questions they still have and send them to the e-mail address.

**ADJUST INSTRUCTION**

Read students’ e-mail questions to the class, and ask for volunteers to answer them. Encourage students to raise any other questions they have.

**Build Science Skills**

Tell students that transcription promotion, which is shown in *Figure 13–17*, is just one way that eukaryotic genes can be regulated. They can also be regulated by transcription repression. Create a class diagram on the board that shows how repressor proteins could control transcription in eukaryotes. (The diagram should resemble the part of *Figure 13–16* that shows transcription repression in prokaryotes.)

**DIFFERENTIATED INSTRUCTION**

**ELL** English Language Learners Have students begin a KWL Chart about eukaryotic gene regulation before they start reading about it in the lesson. Ask them to make predictions about eukaryotic gene regulation based on what they already know about gene regulation in prokaryotes. Tell them to list their predictions in column K. In column W, they should write questions they would like to have answered. Have them try to find answers to the questions as they read and record their answers in column L.

**Study Wkbks A/B, Appendix S27, KWL Chart. Transparencies, GO11.**

**Mystery Clue** Sample answer: The researchers attached a new promoter sequence to the mouse eye gene so that RNA polymerase would have a point to start transcription of the gene. Students can go online to *Biology.com* to gather their evidence.

**Address Misconceptions**

Control of Gene Expression Students often fail to understand the importance of regulatory genes in gene expression. Address this lack of understanding by pointing out that genes coding for repressor proteins and other regulatory proteins are an important part of the genome of even single-celled organisms such as bacteria. The lac operon is just one, well-studied example. Stress how the specialized cells of multicellular eukaryotes make gene regulation even more important.

**Answers**

**IN YOUR NOTEBOOK** In a single-celled organism, if a gene is turned on, it is turned on in the entire organism. In single-celled organisms, genes are usually regulated by repressor proteins that bind to operons or other substrates and prevent or allow the transcription of groups of genes. In a multicellular organism, cells are specialized. Each cell can have a unique set of genes that are turned on at any given moment.
Cell Specialization  Why is gene regulation in eukaryotes more complex than in prokaryotes? Think for a moment about the way in which genes are expressed in a multicellular organism. The genes that code for liver enzymes, for example, are not expressed in nerve cells. Keratin, an important protein in skin cells, is not produced in blood cells. Cell specialization requires genetic specialization, yet all of the cells in a multicellular organism carry the same genetic code in their nucleus. Complex gene regulation in eukaryotes is what makes specialization possible.

RNA Interference  For years biologists wondered why cells contain lots of small RNA molecules, only a few dozen bases long, that don’t belong to any of the major groups of RNA (mRNA, tRNA, or rRNA). In the last decade, a series of important discoveries has shown that these small RNA molecules play a powerful role in regulating gene expression. And they do so by interfering with mRNA.

As Figure 13–18 shows, after they are produced by transcription, the small interfering RNA molecules fold into double-stranded hairpin loops. An enzyme called the “Dicer” enzyme cuts, or dices, these double-stranded loops into microRNA (miRNA), each about 20 base pairs in length. The two strands of the loops then separate. Next, one of the miRNA pieces attaches to a cluster of proteins to form what is known as a silencing complex. The silencing complex binds to and destroys any mRNA containing a sequence that is complementary to the miRNA. In effect, miRNA sticks to certain mRNA molecules and stops them from passing on their protein-making instructions.

The silencing complex effectively shuts down the expression of the gene whose mRNA it destroys. Blocking gene expression by means of an miRNA silencing complex is known as RNA interference. At first, RNA interference (RNAi) seemed to be a rare event, found only in a few plants and other species. It’s now clear that RNA interference is found throughout the living world and that it even plays a role in human growth and development.

Biology In-Depth

TREATING DISEASE USING RNA INTERFERENCE

Soon after RNA interference was discovered, scientists began exploring ways that it might be used to treat or cure diseases. The aim was to develop artificial miRNA molecules that could turn off the expression of disease-causing genes. One of the first diseases to be studied was macular degeneration, which is the primary cause of adult blindness in the U.S. The disease occurs when a protein stimulates overgrowth of capillaries in the eye. An RNAi drug was developed that shuts down the expression of the gene coding for this protein. The drug can be injected directly into the eye. This is important because a drug injected into the blood might prevent the expression of this gene in parts of the body where it is needed. Researchers are also trying to find RNAi treatments for cancer, AIDS, hepatitis C, and Huntington’s disease.

Answers

FIGURE 13–18  That mRNA sequence is destroyed and not translated.
The Discovery of RNA Interference

In 1998, Andrew Fire and Craig Mello carried out an experiment that helped explain the mechanism of RNA interference. They used RNA from a large gene called unc-22, which codes for a protein found in muscle cells. They prepared short mRNA fragments corresponding to two exon regions of the gene and injected them into egg cells of the worm **C. elegans**. Some of their results are shown in the table.

<table>
<thead>
<tr>
<th>Portion of Gene Used to Produce mRNA</th>
<th>Strand Injected</th>
<th>Result in Adult Worm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unc-22 (exon 21–22)</td>
<td>Sense</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>Antisense</td>
<td>Normal</td>
</tr>
<tr>
<td>Unc-22 (exon 27)</td>
<td>Sense + Antisense</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>Antisense</td>
<td>Normal</td>
</tr>
</tbody>
</table>

1. **Draw Conclusions** How did the adult worms’ responses differ to injections of single-stranded mRNA (the “sense” strand), its complementary strand (“antisense”), and double-stranded RNA (“sense + antisense”)?

2. **Form a Hypothesis** Twitching results from the failure of muscle cells to control their contractions. What does this suggest about the unc-22 protein in some of the worms? How would you test your hypothesis?

3. **Infer** The injected fragments came from two different places in the gene and were only a few hundred bases long. The unc-22 mRNA is thousands of bases long. What does this suggest about the mechanism of RNA interference?

The Promise of RNAi Technology

The discovery of RNAi has made it possible for researchers to switch genes on and off at will, simply by inserting double-stranded RNA into cells. The Dicer enzyme then cuts this RNA into miRNA, which activates silencing complexes. These complexes block the expression of genes producing miRNA complementary to the miRNA. Naturally this technology is a powerful way to study gene expression in the laboratory. However, RNAi technology also holds the promise of allowing medical scientists to turn off the expression of genes from viruses and cancer cells, and it may provide new ways to treat and perhaps even cure diseases.

Genetic Control of Development

What controls the development of cells and tissues in multicellular organisms?

Regulating gene expression is especially important in shaping the way a multicellular organism, like the mouse embryo in **Figure 13–19**, develops. Each of the specialized cell types found in the adult originates from the same fertilized egg cell. Cells don’t just grow and divide during embryonic development. As the embryo develops, different sets of genes are regulated by transcription factors and repressors. Gene regulation helps cells undergo differentiation, becoming specialized in structure and function. The study of genes that control development and differentiation is one of the most exciting areas in biology today.

**Infer** The injected fragments came from two different places in the gene and were only a few hundred bases long. The unc-22 mRNA is thousands of bases long. What does this suggest about the mechanism of RNA interference?

**FIGURE 13–19 Differentiation**

This scanning electron micrograph shows a mouse embryo undergoing cell differentiation 13.5 days after conception.

*RNA and Protein Synthesis 381*

**Connect to Health**

After students read about the promise of RNA interference technology, challenge them to explain how the technology could be used to treat a specific genetic disease. Explain that Huntington’s disease is caused by a single autosomal dominant mutant gene. The gene produces a protein that causes brain abnormalities, which in turn interfere with coordination, speech, and mental abilities.

**Ask** How might RNA interference technology be used to treat Huntington’s disease? (An miRNA molecule complementary to the mutant gene that causes Huntington’s disease might be injected into a person with the gene. The miRNA would prevent the expression of the gene so that its protein could not be produced. This would prevent the disease from developing.)

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** Use a **Quick Write** strategy to check students’ understanding of the difficult topics of RNA interference and RNA interference technology. Give them one or two minutes to write down everything they know about the topics. Then, read their responses and identify anything they don’t understand. Clarify these issues before moving on to the next topic.

**Study Wkbks A/B, Appendix S11, Quick Write.**

**Advanced Students** Assign one of the following diseases to each of five students: macular degeneration, cancer, AIDS, hepatitis C, or Huntington’s disease. Tell them to find reports of research investigating the use of RNA interference to treat their assigned disease. Ask them to make a list of the most student-friendly research reports to share with the class.

**PURPOSE** Students will analyze data to infer how RNA interference works.

**PLANNING** Make sure students understand the role of double-stranded RNA in RNA interference by reviewing **Figure 13–18**.

**ANSWERS**

1. For both portions of the gene, injection of single-stranded mRNA produced adult worms with normal responses, whereas injection of double-stranded mRNA produced adult worms with twitching responses.

2. **Sample answer:** In worms with the twitching response, the unc-22 protein that controls muscle contractions was not produced. I would test this hypothesis by determining whether the protein was present in the worms with the twitching response.

3. **Sample answer:** RNA interference may prevent a gene from being expressed by interfering with just a small percentage of its bases.
LESSON 13.4

Use Models

Use a simple model to help students understand how homeobox genes control development. Stand about 20 dominoes on end in a long row. The dominoes should be spaced so that knocking over the first domino will cause a cascade effect that knocks over the rest of the dominoes. Say that the first five dominoes represent a homeobox gene and the other dominoes represent genes that control the development of an organ. Have students observe what happens to the other dominoes when you knock over the first domino. Explain how this models the effects of a homeobox gene on genes that control development. Set up the dominoes again, and then remove the second through fifth dominoes from the row. Say that this represents a mutation in the homeobox gene. Demonstrate how knocking over the first domino no longer causes the cascade effect. Ask students to infer how a mutation in a homeobox gene might affect an organism’s development.

DIFFERENTIATED INSTRUCTION

**Less Proficient Readers** On the board, write the term “differentiation” and separate it into its parts (different and -ation). Explain that -ation means “process of.”

**Ask** What do you think differentiation means? (process of making things different)

**Ask** What does cell differentiation mean? (process of making cells different)

Describe concrete examples of differentiated cells, such as skin and blood cells. Point out specific ways they differ. Then, explain how gene regulation is involved in the differentiation of cells.

Students are likely to infer that homeobox genes control the growth and development of eyes in flies and mice.

Students can go online to Biology.com to gather their evidence.

Answers

**FIGURE 13–20** the back of the body (posterior portion of the abdomen of the fruit fly and rump of the mouse)

**Homeotic Genes** The American biologist Edward B. Lewis was the first to show that a specific group of genes controls the identities of body parts in the embryo of the common fruit fly. Lewis found that a mutation in one of these genes actually resulted in a fly with a leg growing out of its head in place of an antenna! From Lewis’s work it became clear that a set of master control genes, known as **homeotic genes**, regulates organs that develop in specific parts of the body.

**Homeobox and Hox Genes** Molecular studies of homeotic genes show that they share a very similar 180-base DNA sequence, which was given the name homeobox. **Homeobox genes** code for transcription factors that activate other genes that are important in cell development and differentiation. Homeobox genes are expressed in certain regions of the body, and they determine factors like the presence of wings or legs.

In flies, a group of homeobox genes known as **Hox genes** are located side by side in a single cluster, as shown in **Figure 13–20**. Hox genes determine the identities of each segment of a fly’s body. They are arranged in the exact order in which they are expressed, from anterior to posterior. A mutation in one of these genes can completely change the organs that develop in specific parts of the body.

Remarkably, clusters of Hox genes exist in the DNA of other animals, including humans. These genes are arranged in the same way—from head to tail. The function of Hox genes in humans seems to be almost the same as it is in fruit flies: They tell the cells of the body how to differentiate as the body grows. What this means, of course, is that nearly all animals, from flies to mammals, share the same basic tools for building the different parts of the body.

The striking similarity of master control genes—genes that control development—has a simple scientific explanation. Common patterns of genetic control exist because all these genes have descended from the genes of common ancestors. **Master control genes** are like switches that trigger particular patterns of development and differentiation in cells and tissues. The details can vary from one organism to another, but the switches are nearly identical. Recent studies have shown that the very same Hox gene that triggers the development of hands and feet is also active in the fins of certain fish.

**How Science Works**

**DISCOVERY OF HOMEBOX GENES**

The discovery of homeobox genes by Edward B. Lewis provided an explanation for something scientists had observed 200 years before but had never been able to explain: the similarity in basic body plans of animals as diverse as insects and humans. In the early 1800s, French zoologist Étienne Geoffroy Saint-Hilaire noted that vertebrates are basically arthropods turned upside down. Around the same time, German embryologist Karl Ernst von Baer demonstrated that vertebrate embryos were all virtually identical. When Lewis identified homeobox genes in fruit flies in the mid-1900s, these observations suddenly made sense. The evolution of gene sequencing technologies over the next few decades allowed scientists to sequence the homeobox genes. Since then, nearly identical homeobox genes have been found in many vertebrates, including humans. This discovery has had a profound influence on the study of evolution.
Environmental Influences  You’ve seen how cell differentiation is controlled at least in part by the regulation of gene expression. Conditions in an organism’s environment play a role too. In prokaryotes and eukaryotes, environmental factors like temperature, salinity, and nutrient availability can influence gene expression. One example: The lac operon in E. coli is switched on only when lactose is the only food source in the bacteria’s environment.

Metamorphosis is another well-studied example of how organisms can modify gene expression in response to change in their environment. Metamorphosis involves a series of transformations from one life stage to another. It is typically regulated by a number of external (environmental) and internal (hormonal) factors. As organisms move from larval to adult stages, their body cells differentiate to form new organs. At the same time, old organs are lost through cell death.

Consider the metamorphosis of a tadpole into a bullfrog, as shown in Figure 13–21. Under less than ideal conditions—a drying pond, a high density of predators, low amounts of food—tadpoles may speed up their metamorphosis. In other words, the speed of metamorphosis is determined by various environmental changes that are translated into hormonal changes, with the hormones functioning at the molecular level. Other environmental influences include temperature and population size.

FIGURE 13–21 Metamorphosis Environmental factors can affect gene regulation. If the bullfrog’s environment changes for the worse, its genes will direct the production of hormones to speed the transformation of the tadpole (top photo) to the adult bullfrog (bottom photo).

Assess and RemEDIATE

EVALUATE UNDERSTANDING
Ask students to write a list of steps that occur in eukaryote gene regulation. Have them compare lists with a partner and discuss any discrepancies. Then, have students complete the 13.4 Assessment.

REMEDIATION SUGGESTION

Struggling Students If students have trouble with Question 4, review the role of repressors and transcription factors in gene regulation. Remind students that repressors, transcription factors, and hormones are proteins.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.
Pre-Lab
Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab
Tell students they will perform the chapter lab From DNA to Protein Synthesis described in Lab Manual A.

Struggling Students
A simpler version of the chapter lab is provided in Lab Manual B.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 326.

Pre-Lab Answers

BACKGROUND QUESTIONS
a. mRNA, because the sequence contains uracil instead of thymine.

b. Sample answer: During both transcription and translation, large molecules are synthesized from smaller units. During transcription, nucleotides are assembled into complementary mRNA molecules. During translation, amino acids are assembled into proteins.

c. DNA, mRNA, tRNA, amino acid

PRE-LAB QUESTIONS
1. Transcribe the DNA to mRNA; translate the mRNA to amino acids, find the single-letter abbreviation for each amino acid.

2. In protein synthesis, a stop codon is used to mark the end of a protein synthesis. In the coded messages, stop codons are used to represent spaces between words.

3. The letters B, J, O, U, X, and Z will not appear in the messages because these letters are not used as single-letter abbreviations for amino acids.
Mutations often produce proteins with new or altered functions that can be useful to organisms in different or changing environments.

- mutation (372)
- mutagen (375)
- point mutation (373)
- polyplody (376)
- frameshift mutation (373)

13.4 Gene Regulation and Expression

- DNA-binding proteins in prokaryotes regulate genes by controlling transcription.
- By binding DNA sequences in the regulatory regions of eukaryotic genes, transcription factors control the expression of those genes.
- Master control genes are like switches that trigger particular patterns of development and differentiation in cells and tissues.

Think Visually

Using the information in this chapter, complete the following flowchart about protein synthesis:

1. Translation begins at the start codon.
2. The polypeptide is complete.

13.2 Ribosomes and Protein Synthesis

- The genetic code is read three “letters” at a time, so that each “word” is three bases long and corresponds to a single amino acid.
- Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains.
- The central dogma of molecular biology is that information is transferred from DNA to RNA to protein.

- polypeptide (366)
- genetic code (366)
- codon (366)
- translation (368)
- anticodon (369)
- gene expression (370)

13.3 Mutations

- Mutations are heritable changes in genetic information.
- The effects of mutations on genes vary widely. Some have little or no effect; some produce beneficial variations. Some negatively disrupt gene function.

Performance Tasks

SUMMATIVE TASK Ask students to write a newspaper story reporting on a “case” of gene regulation. All the factors involved in gene regulation (genes, transcription factors, repressor proteins, RNA polymerase, regulatory sites) should appear as characters in the story. The story should be a journalistic-style account of events and describe what happens to the characters as the events unfold.

TRANSFER TASK Have groups of students write a research proposal about RNA interference technology and a particular genetic disease. The proposal should have the following sections: Research Question, Literature Review, Research Hypothesis, Research Plan, What the Research Will Show, and Why the Research Is Important. Make sure students do an actual literature review before they write their proposal.

Answers

THINK VISUALLY

1. Sample answer: mRNA is transcribed and edited in the nucleus and then goes to a ribosome in the cytoplasm.

2. Sample answer: As the ribosome reads each codon, tRNA brings the correct amino acid to the ribosome, where it is attached to other amino acids in a growing polypeptide. This continues until a “stop” codon is reached.
Lesson 13.1

UNDERSTAND KEY CONCEPTS
1. b
2. b
3. Messenger RNA carries the instructions for protein synthesis from DNA to the cytoplasm. Ribosomal RNA makes up ribosomes, where proteins are made. Transfer RNA carries amino acids to the ribosome and matches them to the coded mRNA message.
4. The enzyme knowns to start transcribing DNA at a promoter, which is a region of DNA that has specific base sequences.
5. Introns are sections of mRNA that are not needed for protein synthesis. Exons are sections of mRNA that are needed for protein synthesis.

THINK CRITICALLY
6. UGGCAGUG
7. If the intron were not removed, its codons would be translated and become part of a protein. As a result, the protein might not function properly.

Lesson 13.2

UNDERSTAND KEY CONCEPTS
8. c
d
10. c
c
11. c
12. a three-base code “word” in the genetic code that specifies a particular amino acid, start, or stop
13. At the ribosome, anticodons in tRNA form bonds with the complementary codons in mRNA, and tRNA adds its amino acid to the polypeptide chain.
14. mRNA: GAU; tRNA: CUA
15. Proteins determine the characteristics of organisms because they are like microscopic tools, each specifically designed to build or operate a component of a living cell. Therefore, controlling the proteins in an organism controls the organism’s characteristics.

THINK CRITICALLY
16. Transcription in genetics means to “write out” the genetic code in DNA in the form of a strand of mRNA. The message in mRNA is still in the same “language,” the genetic code. Translation in genetics means to express the codons in mRNA in a different “language,” that is, as a chain of amino acids instead of as a string of codons.
17. The appearance of the sequence AAC does not necessarily mean that asparagine will appear in the protein. That nucleotide sequence could be part of an intron and edited out of the RNA before it leaves the nucleus and becomes involved in protein synthesis. Or, the nucleotide sequence AAC could appear in a long strand of RNA and could be divided over two codons (such as, GGA-ACC).

Lesson 13.3

UNDERSTAND KEY CONCEPTS
18. b
19. d
20. b
21. Sample answer: gene mutations and chromosomal mutations. An example of a gene mutation is an insertion mutation, in which an extra base is inserted into a codon. An example of a chromosomal mutation is an inversion, in which part of a chromosome is reversed. Gene mutations affect a single gene; whereas chromosomal mutations affect all or part of a chromosome.
13.3 Mutations

Understand Key Concepts

18. Changes in DNA sequences that affect genetic information are known as
   a. replications.  c. transformations.
   b. mutations.  d. translations.

19. A single-base mutation in a messenger RNA molecule could transcribe the DNA sequence CAGTAT into
   a. GTCATA.  c. GTCTUA.
   b. GUCUA.  d. GUAUA.

20. A substance that can cause a change in the DNA code of an organism is called
   a. toxin.  c. nitrogenous base.
   b. mutagen.  d. nucleotide.

21. Name and give examples of two major types of mutations. What do they have in common? How are they different?

22. How does a deletion mutation differ from a substitution mutation?

23. Can mutations have a positive effect?

Think Critically

24. Compare and Contrast How does the possible impact of a chromosomal mutation that occurs during meiosis differ from that of a similar event that occurs during mitosis of a body cell that is not involved in reproduction?

25. Apply Concepts A mutation in the DNA of an organism changes one base sequence in a protein-coding region from CAC to CAT. What is the effect of the mutation on the final protein? Explain your answer.

13.4 Gene Regulation and Expression

Understand Key Concepts

26. An expressed gene
   a. functions as a promoter.
   b. is transcribed into RNA.
   c. codes for just one amino acid.
   d. is made of mRNA.

22. A deletion mutation occurs when a base is lost from a codon. This shifts the “reading frame,” so all the codons after the point of deletion are affected. A substitution mutation occurs when a single base is replaced by a different base. This does not shift the “reading frame.”

23. Yes, a mutation could produce a protein with a new or altered function that might be useful to an organism in a changing environment.

THINK CRITICALLY

24. A chromosomal mutation that occurs during meiosis will be carried by some of the organism’s gametes and possibly to the organism’s offspring. A mutation that occurs during mitosis in a body cell will be passed on to that cell’s daughter cells but not to the organism’s offspring.

25. The mutation in the DNA changes the codon in mRNA from GUG to GUA. Both of these codons code for the amino acid valine, so the final protein would not be affected.

MOUSE-EYED FLY

Years ago geneticists discovered a fly gene called eyeless. Mutations that inactivate this gene cause flies to develop without eyes. Geneticists later discovered a mouse gene, called Pax6, that was homologous to eyeless. Transplanting an activated Pax6 gene into a fruit fly can cause the fly to grow eyes in odd places. This happens despite the fact that mouse eyes and fly eyes are very different. In fact the only reason we describe them as “eyes” is because they make vision possible.

How can the Pax6 gene perform the same role in such diverse animals? It probably began very early in the history of life, when eyes were just patches of light-sensitive cells on the skin of the common ancestors of all animals. As those organisms evolved and diversified, master control genes like Pax6 kept working, but with altered functions. Many genes like Pax6 are shared, not only by insects, but by all animals, including worms, sea urchins, and humans.

1. Compare and Contrast How are fly eyes and mouse eyes different? Similar?

2. Infer The Pax6 and eyeless genes code for transcription factors, not for parts of the actual eye. Why does this make sense in light of the effect of Pax6 when it is inserted into a fly?

3. Connect to the Big Idea What feature of the genetic code makes it possible for a mouse gene to work inside the cell of a fly?

After students have read through the Chapter Mystery, ask them what the Pax6 gene controls in both mice and fruit flies. (Devlopment of eyes) Then, ask them to infer what type of gene Pax6 likely is. (It is likely a homeobox gene, because it controls other genes that are responsible for development of major body structures.)

CHAPTER MYSTERY ANSWERS

1. Fly eyes and mouse eyes look very different and have different structures. However, both types of eyes have the same function. They sense light and make vision possible.

2. If the Pax6 gene coded for parts of the actual eye, then the fly would develop mouse eyes in addition to normal fly eyes when the gene was inserted. Instead, Pax6 causes the fly to develop extra fly eyes. This makes sense if Pax6 codes for transcription factors that turn on other genes in the fly, which in turn code for the parts of the actual fly eye.

3. A mouse gene can work inside the cell of a fly because the genetic code is nearly universal. In virtually all organisms, codons are read three bases at a time and in the same order, and the codons code for the same amino acids.

In the Untamed Science Video: Tales of a Mutant Leopard, the crew leads students on a field trip to see how some species benefit from mutations.
Lesson 13.4

USE SCIENCE GRAPHICS

35. no effect

36. Sample answer: Substituting a C for a G in the first base of a codon that codes for valine would replace it with leucine. Substituting a C for a U in the second base of a codon that codes for valine would replace it with alanine. These substitutions may alter the function of the resulting protein.

WRITE ABOUT SCIENCE

37. Student explanations should address neutral, harmful, and beneficial mutations and explain ways in which each may occur.

38. DNA is transcribed to form mRNA. After the mRNA is edited, it leaves the nucleus and enters the cytoplasm. A ribosome containing rRNA attaches to the mRNA strand and translates it to form a polypeptide. In translation, tRNA molecules bring the correct amino acids to the ribosome to add to the polypeptide.
Answers

1. C
2. C
3. B
4. D
5. A
6. C
7. C
8. D

9. The lac repressor system controls the production of enzymes needed to digest lactose. When lactose is absent and the enzymes are not needed, repressor proteins turn off the genes, so that the enzymes are not produced. When lactose is present and the enzymes are needed, lactose prevents the repressor proteins from turning off the genes, so that the enzymes are produced.

Open-Ended Response

9. What is the function of the lac repressor system in E. coli?
Connect to the Big Idea

Have students examine the photo and discuss the ways the people look different from one another and the ways they look similar. Help students connect the caption to the Big Idea of Information and Heredity by asking them to recall the role of DNA and its significance in heredity. (DNA carries the complete blueprint of an organism. Genetic information is passed from one generation to the next in the form of genes, which are coded segments of DNA.) Remind students that organisms resulting from sexual reproduction inherit a unique combination of genes. Point out that the chapter specifically covers the genetics of humans. Then, ask students to offer reasons for studying human inheritance. (They will probably mention the value of studying inherited diseases to try to find cures.) Read aloud the question, How can we use genetics to study human inheritance? Have students anticipate an answer. Then, tell them to keep the question in mind as they study the chapter.

CHAPTER MYSTERY

Have students read over the Chapter Mystery and make predictions about how sickle cell disease is inherited. Have them discuss how Ava might use genetics to help her find out if she is at risk for sickle cell disease.

Have students preview the chapter vocabulary using the Flash Cards.

Understanding by Design

In Unit 4, students are building toward the Enduring Understanding that DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics. The graphic organizer at the right shows how chapter content informs the Enduring Understanding.

PERFORMANCE GOALS

In Chapter 14, students learn about patterns of human heredity and how genetics is used to study human inheritance. Students will apply their knowledge of human genetics by constructing models, writing explanations, and developing analogies to show they understand key concepts. At the end of the chapter, students will develop a comprehensive interview with a geneticist and write a letter expressing an opinion about genetic testing.
One thing to notice about this group of students is that none of them looks alike. The diversity of traits among the human race stems from one microscopic molecule—DNA.

THE CROOKED CELL
When Ava visited her Uncle Eli in the hospital, he appeared tired and pale. He complained of sharp pains in his bones. “I’ve got sickle cell disease,” Uncle Eli explained, short of breath. “I just hope it doesn’t run in your side of the family.”

That evening, Ava searched the Internet for information about her uncle’s disease. She saw photos of red blood cells shaped like the letter C—a far cry from the healthy, round blood cells of a normal individual. Ava learned that these sickle-shaped cells are rigid and sticky. In blood vessels, they form clumps that can block blood flow and even cause organ damage. “Am I at risk?” Ava wondered. To find out, she would need to investigate her family history—and her own cells. As you read this chapter, look for clues that would help Ava discover whether she might carry sickle cell trait. Then, solve the mystery.

Never Stop Exploring Your World.
Finding out about Ava’s risk of sickle cell disease is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

CHAPTER MYSTERY
As a young woman probes into her family history to ascertain her risk of sickle cell trait, students use their knowledge of human heredity to find the answer along with her.

UNTAMED SCIENCE VIDEO
Take a trip with the crew of Untamed Science into the microscopic world of chromosomes to find out how colorblindness is inherited.

ART REVIEW
Drag-and-drop items allow students to construct a karyotype.

DATA ANALYSIS
Students analyze the connection between blood type O and a higher susceptibility to cholera.

INTERACTIVE ART
Students can interact with pedigrees online.

TUTOR TUBE
Short, online tutorial shows how pedigrees help students understand how a trait can “skip a generation.”

ART IN MOTION
Students watch an animation that shows how non-disjunction occurs during meiosis.

Chapter 14
Big Idea:
Information and Heredity

Chapter 14 EQ:
How can we use genetics to study human inheritance?

14.1 GQ: How does studying the human genome help us draw conclusions about the inheritance of traits?

14.2 GQ: What causes some human genetic disorders?

14.3 GQ: How do we study the human genome, and what have we learned so far?
Getting Started

Objectives

14.1.1 Identify the types of human chromosomes in a karyotype.
14.1.2 Describe the patterns of the inheritance of human traits.
14.1.3 Explain how pedigrees are used to study human traits.

Student Resources

Study Workbooks A and B, 14.1 Worksheets
Spanish Study Workbook, 14.1 Worksheets

Activate Prior Knowledge

Ask students if they know what a dog pedigree is or if any of them owns a dog with a pedigree. (A pedigree is a record of the family tree, usually back at least three generations.) Explain that a pedigree is often used to show a dog is a purebred, and it gives information about the dog’s background and any hereditary health problems in its blood line. Tell them that human pedigrees also are used to show information about a person’s background, most commonly to trace genetic disorders.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

II

CONTENT

C.1.d, C.2.a, C.2.b

INQUIRY

A.1.b, A.1.c, A.1.d, A.2.d

Human Chromosomes

THINK ABOUT IT

If you had to pick an ideal organism for the study of genetics, would you choose one that produced lots of offspring? How about one that was easy to grow in the lab? Would you select one with a short life span in order to do several crosses per month? How about all of the above? You certainly would not choose an organism that produced very few offspring, had a long life span, and could not be grown in a lab. Yet, when we study human genetics, this is exactly the sort of organism we deal with. Given all of these difficulties, it may seem a wonder that we know as much about human genetics as we do.

Karyotypes

What is a karyotype?

What makes us human? We might try to answer that question by looking under the microscope to see what is inside a human cell. Not surprisingly, human cells look much like the cells of other animals. To find what makes us uniquely human, we have to look deeper, into the genetic instructions that build each new individual. To begin this undertaking, we have to explore the human genome. A genome is the full set of genetic information that an organism carries in its DNA.

The study of any genome starts with chromosomes—those bundles of DNA and protein found in the nuclei of eukaryotic cells. To see human chromosomes clearly, cell biologists photograph cells in mitosis, when the chromosomes are fully condensed and easy to view. Scientists then cut out the chromosomes from the photographs and arrange them in a picture known as a karyotype (kar ee uh typ). A karyotype shows the complete diploid set of chromosomes grouped together in pairs, arranged in order of decreasing size.

FIGURE 14–1 A Human Karyotype

A typical human cell has 23 pairs of chromosomes. These chromosomes have been cut out of a photograph and arranged to form a karyotype.

Teach for Understanding

ENDURING UNDERSTANDING DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION How does studying the human genome help us draw conclusions about the inheritance of traits?

EVIDENCE OF UNDERSTANDING At the end of the lesson, give students the following assessment to show they understand how chromosomes and genes are related to the inheritance of traits. Provide pairs of students with white, red, and green pipe cleaners to represent X and Y chromosomes that do not have the trait for colorblindness and X chromosomes that do. Ask them to model all six possible pairings between males and females with different genotypes for the trait of colorblindness and to construct Punnett squares showing the possible genotype outcomes for the male and female offspring (carrier, normal vision, or colorblind).
The karyotype in Figure 14–1 is from a typical human cell, which contains 46 chromosomes, arranged in 23 pairs. Why do our chromosomes come in pairs? Remember that we begin life when a haploid sperm, carrying just 23 chromosomes, fertilizes a haploid egg, also with 23 chromosomes. The resulting diploid cell develops into a new individual and carries the full complement of 46 chromosomes—two sets of 23.

Sex Chromosomes  Two of the 46 chromosomes in the human genome are known as sex chromosomes, because they determine an individual’s sex. Females have two copies of the X chromosome. Males have one X chromosome and one Y chromosome. As you can see in Figure 14–2, this is the reason why males and females are born in a roughly 50 : 50 ratio. All human egg cells carry a single X chromosome (23,X). However, half of all sperm cells carry an X chromosome (23,X) and half carry a Y chromosome (23,Y). This ensures that just about half the zygotes will be males and half will be females.

More than 1200 genes are found on the X chromosome, some of which are shown in Figure 14–3. Note that the human Y chromosome is much smaller than the X chromosome and contains only about 140 genes, most of which are associated with male sex determination and sperm development.

Autosomal Chromosomes  To distinguish them from the sex chromosomes, the remaining 44 human chromosomes are known as autosomal chromosomes, or autosomes. The complete human genome consists of 46 chromosomes, including 44 autosomes and 2 sex chromosomes. To quickly summarize the total number of chromosomes present in a human cell—both autosomes and sex chromosomes—biologists write 46,XX for females and 46,XY for males.

In Your Notebook Describe what makes up a human karyotype.

**Quick Facts**

**Duchenne Muscular Dystrophy**

Duchenne muscular dystrophy is the most common form of the more than thirty kinds of muscular dystrophy. It is caused by a mutation in a gene on the X chromosome that codes for a muscle protein called dystrophin. The mutated gene causes defects in muscle proteins, leading to muscle degeneration. Because the gene is inherited in an X-linked recessive pattern, the disease affects mainly boys. Many children with the disease cannot walk and require respirators to breathe. Most do not live beyond their 30s. Researchers are experimenting with several approaches to a cure, including gene therapy that involves injecting children with altered viruses that can introduce normal genes to affected cells.
LESSON 14.1

Teach continued

Build Science Skills

Ask students to recall what they know about simple inheritance patterns. Draw a blank Punnett square on the board. Ask them how to label the columns and rows and fill out the cells to show a cross between two people who are both heterozygous for the Rh factor. Have students explain how the results show a pattern of simple dominance. Then, use Figure 14–5 to discuss codominant and multiple alleles. Have students work out crosses between different genotypes to see how different blood types can be inherited.

DIFFERENTIATED INSTRUCTION

Struggling Students Make sure students understand that the superscripts in Figure 14–5 are not exponents or additional alleles but labels that distinguish the two codominant alleles. Have them make a simpler version of the second column in the chart by rewriting the \( P^A \), \( P^B \), and \( i \) alleles as \( A \), \( B \), and \( O \), respectively.

Have students determine the connection between blood type O and a higher susceptibility to cholera in the activity Data Analysis: Blood Types and Cholera.

Address Misconceptions

Frequencies of Dominant and Recessive Traits Some students think that dominant traits are more common in a population. This might stem from their observation that 75 percent of offspring in a heterozygous cross show the dominant trait. Use Punnett squares to show a cross between two homozygous recessive parents and a cross between two heterozygous parents. Point out that a Punnett square shows the phenotype frequencies for a specific cross, not for an entire population. Most individuals in a population will show a recessive trait if the population has many recessive alleles and therefore has more incidents of crosses involving homozygous recessive parents. Emphasize that allele frequencies can be high or low regardless of how the allele is expressed.

Answers

FIGURE 14–5 The allele for no antigens, \( i \), is recessive to \( P^A \) and \( P^B \), so it is hidden by the \( P^A \) and \( P^B \) genes. Thus, two different genotypes—\( P^A i \) and \( P^B i \)—result in the A phenotype, and two other genotypes—\( P^A P^A \) and \( P^B P^B \)—result in the B phenotype.

Transcript of Human Traits

What patterns of inheritance do human traits follow?

It has not been easy studying our species using traditional genetic techniques. Despite the difficulties, human genetics has progressed rapidly, especially in recent years, with the use of molecular techniques to study human DNA. What have these studies shown? Human genes follow the same Mendelian patterns of inheritance as the genes of other organisms.

Dominant and Recessive Alleles Many human traits follow a pattern of simple dominance. For instance, a gene known as \( M C 1 R \) helps determine skin and hair color. Some of \( M C 1R \)’s recessive alleles produce red hair. An individual with red hair usually has two of these recessive alleles, inheriting a copy from each parent. Dominant alleles for the \( M C 1R \) gene help produce darker hair colors.

Another trait that displays simple dominance is the Rhesus, or Rh blood group. The allele for Rh factor comes in two forms: \( Rh^+ \) and \( Rh^- \). \( Rh^- \) is dominant, so an individual with both alleles (\( Rh^+/Rh^- \)) is said to have Rh positive blood. Rh negative blood is found in individuals with two recessive alleles (\( Rh^-/Rh^- \)).

Codominant and Multiple Alleles The alleles for many human genes display codominant inheritance. One example is the ABO blood group, determined by a gene with three alleles: \( P^A \), \( P^B \), and \( i \). Alleles \( P^A \) and \( i \) are codominant. They produce molecules known as antigens on the surface of red blood cells. As Figure 14–5 shows, individuals with alleles \( P^A P^A \) and \( P^A i \) produce both \( A \) and \( B \) antigens, making them blood type AB. The \( i \) allele is recessive. Individuals with alleles \( P^B P^B \) or \( P^B i \) produce only the A antigen, making them blood type A. Those with \( P^A P^B \) or \( P^A i \) alleles are type B. Those homozygous for the \( i \) allele (\( i i \)) produce no antigen and are said to have blood type O. If a patient has AB-negative blood, it means the individual has \( P^A \) and \( P^B \) alleles from the ABO gene and two \( Rh^- \) alleles from the Rh gene.

FIGURE 14–4 Recessive Alleles Some of the recessive alleles of the \( M C 1R \) gene cause red hair. An individual with red hair usually has two of these recessive alleles.

FIGURE 14–5 Human Blood Groups

This table shows the relationship between genotype and phenotype for the ABO blood group. It also shows which blood types can safely be transfused into people with other blood types. Apply Concepts How can there be four different phenotypes even though there are six different genotypes?

<table>
<thead>
<tr>
<th>Blood Groups</th>
<th>Phenotype (Blood Type)</th>
<th>Genotype</th>
<th>Antigen on Red Blood Cell</th>
<th>Safe Transfusions To</th>
<th>Safe Transfusions From</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( P^A i ) or ( i i )</td>
<td>A</td>
<td>A, AB</td>
<td>A, O</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>( P^B i )</td>
<td>B</td>
<td>A, B</td>
<td>A, O</td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>( P^A P^B )</td>
<td>A and B</td>
<td>A</td>
<td>A, B, AB, O</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>( i i )</td>
<td>None</td>
<td>A, B, AB, O</td>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>

Biology In-Depth

**BLOOD TYPES AND TRANSFUSIONS**

Knowing a person’s blood group is critical because using the wrong type of blood for a transfusion can be fatal. Type A and type B red blood cells have antigens for their respective type on their surface. The immune system of a person with type B blood would recognize type A cells as foreign and produce antibodies against the type A antigen, and vice versa. The immune system of a person with type O blood would recognize both A and B cells as foreign and produce antibodies against both type A and type B antigens. People with type AB blood have both type A and type B antigens, so they do not produce antibodies against these types of blood. They are called “universal recipients” because they can receive all types of blood in a transfusion. People with type O blood are called “universal donors” because their red blood cells have no antigens to elicit an antibody response, and thus, their blood can be safely donated to people of all blood types.
Sex-Linked Inheritance  

Because the X and Y chromosomes determine sex, the genes located on them show a pattern of inheritance called sex-linkage. A sex-linked gene is a gene located on a sex chromosome. As you might expect, genes on the Y chromosome are found only in males and are passed directly from father to son. Genes located on the X chromosome are found in both sexes, but the fact that men have just one X chromosome leads to some interesting consequences.

For example, humans have three genes responsible for color vision, all located on the X chromosome. In males, a single defective allele for any of these genes results in colorblindness, an inability to distinguish certain colors. The most common form, red-green colorblindness, occurs in about 1 in 12 males. Among females, however, colorblindness affects only about 1 in 200. Why is there such a difference? In order for a recessive allele, like colorblindness, to be expressed in females, it must be present in two copies—one on each of the X chromosomes. This means that the recessive phenotype of a sex-linked genetic disorder tends to be much more common among males than among females.

How Is Colorblindness Transmitted?

1. Make a data table with the column headings: Trial, Colors, Sex of Individual, and Number of X-Linked Alleles. Draw ten rows under the headings and fill in the numbers 1 through 10 in the Trial column. Label one plastic cup Mother and a second plastic cup Father.
2. The white beans represent X chromosomes. Use a black marker to make a dot on 1 white bean to represent the X-linked allele for colorblindness. Place this bean, plus 1 unmarked white bean, into the cup labeled Mother.
3. Mark a black dot on 1 more white bean. Place this bean, plus 1 red bean, into the cup labeled Father. The red bean represents a Y chromosome.
4. Close your eyes and pick one bean from each cup to represent how each parent contributes to a sex chromosome and a fertilized egg.
5. In your data table, record the color of each bean and the sex of an individual who would carry this pair of sex chromosomes. Also record how many X-linked alleles the individual has. Put the beans back in the cups they came from.
6. Determine whether the individual would have colorblindness.
7. Repeat steps 4 to 6 for a total of 10 pairs of beans.

Analyze and Conclude

1. **Draw Conclusions**  How do human sex chromosomes keep the numbers of males and females roughly equal?
2. **Calculate**  Calculate the class totals for each data column. How many females were colorblind? How many males? Explain these results.
3. **Use Models**  Evaluate your model. How accurately does it represent the transmission of colorblindness in a population? Why?

ANALYZE AND CONCLUDE

1. Only the father's chromosome will determine sex. The chance is 50/50 a child will receive an X chromosome from the father, and 50/50 a child will receive a Y chromosome from the father.
2. About 50 percent of the females and 50 percent of the males will be colorblind. The mother is heterozygous, which means her sons have a 50 percent chance of inheriting the X chromosome that carries the allele for colorblindness. The father is colorblind, which means the daughters have a 50 percent chance of inheriting an X chromosome from each parent that carries the allele for colorblindness.
3. The model represents only one type of cross within a population. In an actual human population, the ratio of colorblind to non-colorblind people will be much lower, because not all parents carry the allele for colorblindness.

Build Science Skills

Help students explore sex-linked inheritance by examining a specific cross involving colorblindness. Have students construct a Punnett square to show a cross between a father with normal vision and a mother who is a carrier of the colorblindness trait. Tell them to use the symbols X^B to represent the dominant allele on the X chromosome and X^b for the recessive one. Refer them to Figure 14–2 for help in constructing the cross.

Ask: What percent of the children have normal vision? (75%)  
Ask: Are both daughters carriers? Explain. (No, only one daughter has the X^b allele.)

DIFFERENTIATED INSTRUCTION

**Advanced Students** Challenge students to infer whether a trait controlled by a dominant allele on the X chromosome is more common in male offspring. (A trait controlled by a dominant allele is not more common in males because females, like males, would need to inherit just one dominant allele to have the trait.) Have students make a Punnett square to show how a sex-linked dominant allele would be passed to offspring.
**Teach continued**

**Use Visuals**

Use Figure 14–7 to explain that a pedigree helps trace inheritance patterns by looking at known phenotypes for a single trait. Copy the pedigree on the board. Have volunteers identify what each of the symbols means. Then, walk students through the pedigree. Remind them that the allele for the white forelock trait is dominant, and given this information, have them identify the phenotype and possible genotypes for each individual as you write them beside the appropriate symbols.

Then, ask students to consider the phenotypes as if the allele for the white forelock trait was recessive rather than dominant. Have them point out where the pedigree shows that this is not possible. *(The gene cannot be recessive because if it were, the parents in the second generation who both show the phenotype would be homozygous recessive and could not have a child who shows the opposite phenotype.)* Reinforce that pedigree analysis provides information on the nature of genes and alleles. Ask students to infer a reason for constructing a pedigree chart. *(to trace the inheritance of genetic disorders)*

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** For students who are having difficulty understanding how a pedigree can help show how traits are inherited, draw a pedigree showing a wife with a genetic disorder and a husband without it who have a daughter with the disorder and a son without it. Ask students whether they can tell if the trait is controlled by a dominant or a recessive allele. *(no)* Extend the pedigree back one generation by adding two parents without the disorder for the wife. Then, ask the same question. *(The trait must be recessive; otherwise, at least one of the wife’s parents would also have the trait.)* Point out that often, the more generations a pedigree has, the more obvious the pattern of inheritance is.

**IN YOUR NOTEBOOK** Answers will vary. Check that students have written three questions and that their answers are accurate. Consider having students work in pairs to quiz each other.

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**ANSWERS**

**Human Pedigrees**

**Check for Understanding**

**VISUAL REPRESENTATION**

Ask students to work in pairs to construct a pedigree that shows the inheritance of a single recessive allele, starting with the first generation having genotypes $Aa \times Aa$ and producing three children that represent all three genotypes that could result from a heterozygous cross. Then, have students extend the pedigree to show the members of a third generation, who represent the possible genotypes produced if each member of the second generation crossed with a person having the genotype $Aa$. Discuss the resulting pedigree as a class.

**ADJUST INSTRUCTION**

If students have trouble identifying the genotypes that result from a cross, draw Punnett squares to show the possibilities. If students are confusing symbols and shading, review Figure 14–7.
By analyzing a pedigree, we can often infer the genotypes of family members. For example, because the white forelock trait is dominant, all the family members in Figure 14–7 lacking this trait must have homozygous recessive alleles. One of the grandfather’s children lacks the white forelock trait, so the grandfather must be heterozygous for this trait.

With pedigree analysis, it is possible to apply the principles of Mendelian genetics to humans. The information gained from pedigree analysis makes it possible to determine the nature of genes and alleles associated with inherited human traits. Based on a pedigree, you can often determine if an allele for a trait is dominant or recessive, autosomal or sex-linked.

**Assessment Answers**

1a. Autosomes are chromosomes that are not sex chromosomes.

1b. Females have two X chromosomes; males have one X chromosome and one Y chromosome.

1c. Sample answer: A karyotype shows the complete set of chromosomes in a cell, and they are displayed in order by size. The number and size of chromosomes varies from one species to the next.

2a. A sex-linked trait is controlled by a recessive allele on the X chromosome. Because males have only one X chromosome, they will show the trait when they inherit an X chromosome with the allele. For a female to show the trait, both of her X chromosomes must have the allele for the trait.

2b. A female child would not survive because males do not have a Y chromosome.

3a. A pedigree shows the presence or absence of a trait over several generations within a family. It can be used to determine inheritance patterns or the possibility of inheritance for a future generation.

3b. A female child would not survive because they have one X chromosome.

4. If students have difficulty finding a family to use for the pedigree, allow them to make up one. Answers will vary but pedigrees should use the standard pedigree symbols and include a key. Students may choose other traits besides facial dimples, such as having a widow’s peak, having attached earlobes, or having a cleft chin.
LESSON 14.2

Human Genetic Disorders

Objectives
14.2.1 Explain how small changes in DNA cause genetic disorders.
14.2.2 Summarize the problems caused by nondisjunction.

Student Resources
Study Workbooks A and B, 14.2 Worksheets
Spanish Study Workbooks, 14.2 Worksheets
Lab Manual B, 14.2 Data Analysis Worksheet


Activate Prior Knowledge
Give students one minute to list the different ways mutations can occur, and then ask volunteers to share their list with the class. Lists might include base substitutions, insertions, deletions, and changes in the number or structure of chromosomes. Remind students that most mutations have little or no effect on an organism, but some can result in serious disorders. Invite students to name genetic disorders they have heard about.

ENDURING UNDERSTANDING DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION What causes some human genetic disorders?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how changes in individual genes can cause disorders. Have students imagine they are a genetic counselor who must explain to prospective parents how the genes for sickle cell disease, cystic fibrosis, or Huntington’s disease are inherited and how they cause disease. Students should choose one disorder and write a summary of what they would say to the parents. The language they use should be conversational and easily understood by people who have no specialized background in genetics.

THINK ABOUT IT Have you ever heard the expression “It runs in the family”? Relatives or friends might have said that about your smile or the shape of your ears, but what could it mean when they talk of diseases and disorders? What, exactly, is a genetic disorder?

From Molecule to Phenotype
How do small changes in DNA molecules affect human traits?
We know that genes are made of DNA and that they interact with the environment to produce an individual organism’s characteristics, or phenotype. However, when a gene fails to work or works improperly, serious problems can result.

Molecular research techniques have shown us a direct link between genotype and phenotype. For example, the wax that sometimes builds up in our ear canals can be one of two forms: wet or dry. People of African and European ancestry are more likely to have wet earwax—the dominant form. Those of Asian or Native American ancestry most often have the dry form, which is recessive. A single DNA base in the gene for a membrane-transport protein is the culprit. A simple base change from guanine (G) to adenine (A) causes this protein to produce dry earwax instead of wet earwax.

The connection between molecule and trait, and between genotype and phenotype, is often that simple, and just as direct. Changes in a gene’s DNA sequence can change proteins by altering their amino acid sequences, which may directly affect one’s phenotype. In other words, there is a molecular basis for genetic disorders.

Disorders Caused by Individual Genes Thousands of genetic disorders are caused by changes in individual genes. These changes often affect specific proteins associated with important cellular functions.

Sickle Cell Disease This disorder is caused by a defective allele for beta-globin, one of two polypeptides in hemoglobin, the oxygen-carrying protein in red blood cells. The defective polypeptide makes hemoglobin a bit less soluble, causing hemoglobin molecules to stick together when the blood’s oxygen level decreases. The molecules clump into long fibers, forcing cells into a distinctive sickle shape, which gives the disorder its name.

Sickle-shaped cells are more rigid than normal red blood cells, and, therefore, they tend to get stuck in the capillaries—the narrowest blood vessels in the body. If the blood stops moving through the capillaries, damage to cells, tissues, and even organs can result.
**Cystic Fibrosis** Known as CF for short, cystic fibrosis is most common among people of European ancestry. CF is caused by a genetic change almost as small as the earwax allele. Most cases result from the deletion of just three bases in the gene for a protein called cystic fibrosis transmembrane conductance regulator (CFTR). CFTR normally allows chloride ions (Cl⁻) to pass across cell membranes. The loss of these bases removes a single amino acid—phenylalanine—from CFTR, causing the protein to fold improperly. The misfolded protein is then destroyed. With cell membranes unable to transport chloride ions, tissues throughout the body malfunction.

People with one normal copy of the CF allele are unaffected by CF because they can produce enough CFTR to allow their cells to work properly. Two copies of the defective allele are needed to produce the disorder, which means the CF allele is recessive. Children with CF have serious digestive problems and produce thick, heavy mucus that clogs their lungs and breathing passageways.

**Huntington’s Disease** Huntington’s disease is caused by a dominantly inherited allele for a protein found in brain cells. The allele for this disease contains a long string of bases in which the codon CAG—coding for the amino acid glutamine—repeats over and over again, more than 40 times. Despite intensive study, the reason why these long strings of glutamine cause disease is still not clear. The symptoms of Huntington’s disease, namely mental deterioration and uncontrollable movements, usually do not appear until middle age. The greater the number of codon repeats, the earlier the disease appears, and the more severe are its symptoms.

**Quick Facts**

### FOUNDER EFFECT AND HUNTINGTON’S DISEASE

One of the highest known frequencies of Huntington’s disease is found in the Afrikaner population of South Africa. Researchers have discovered that the affected persons are descendants of a settler from the Netherlands who arrived there in the 1600s. This phenomenon of one or a few individuals with a genetic abnormality causing the establishment of a new population is known as the founder effect. The founder effect is most likely to occur in remote areas where the total population is relatively small. (The founder effect is discussed in Chapter 17.)

**Answers**

**FIGURE 14–8** Exactly one codon (three nucleotide bases) has been deleted, so the rest of the reading frame has not been affected.

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**Teach**

**Use Visuals**

Walk through Figure 14–8 with students to help them understand the biochemistry of cystic fibrosis. Discuss how a deletion mutation can affect protein folding. Ask students how protein folding relates to protein function. (If proteins do not fold properly, they sometimes cannot function.) Ask students to infer whether chloride ions can cross cell membranes by simply passing through the lipid bilayer without the aid of a protein. (They must not be able to cross on their own, because a lack of the CFTR proteins results in a disease.)

**DIFFERENTIATED INSTRUCTION**

**ELL Special Needs** Demonstrate how a deletion can cause a protein to not function. Model protein folding by wrapping a long pipe cleaner (representing a polypeptide chain) around a thick marker. Remove the marker so that the pipe-cleaner coils form a tube shape (representing the final folded protein). Demonstrate that the model protein is a functioning ion channel by passing a marble (representing a chloride ion) through the tube. Model the mutation of the protein by folding one of the coils inward so that it blocks the passage of the marble through the tube.

**Focus on ELL: Access Content**

**ALL SPEAKERS** Pair beginning and intermediate speakers with advanced or advanced high speakers. Give them a few minutes to preview the lesson, reading the headings and boldface Key Concepts, and looking at the diagrams and maps. Then, ask them to predict what they think they will learn. The pairs should discuss their predictions orally and then record them. Beginning and intermediate speakers may draw pictures or write in words or phrases.
Lead a Discussion
Discuss with students the idea that location and other environmental factors can determine whether an allele is beneficial or harmful for a population. For example, for people who live in areas where malaria is common, a gene pool that contains the sickle cell allele is beneficial. In these areas, the “fittest” people are those with one sickle cell allele.

Ask Why is having no copies or two copies of the abnormal allele a disadvantage? (The people with two normal alleles are more likely to get malaria, and the ones with two abnormal alleles are more likely to have sickle cell disease.)

Ask How would displacing members of the population to areas where malaria is not present change whether the allele is a genetic advantage? (In areas where malaria does not exist, it is no longer an advantage to be a carrier. It is only a disadvantage in that you could have children with the disease.) Then, have students identify how changes in public sanitation might have changed how a population may or may not benefit from having individuals that carry one CF allele. (As sanitation improves and typhoid becomes less common, the population benefits less from having the CF allele.)

DIFFERENTIATED INSTRUCTION

Struggling Students Some students may have difficulty reconciling the evolutionary benefit of protection against malaria with the drawback of a fatal disease. Tell them that about 100,000 people worldwide die annually of sickle cell disease, but malaria kills about 1,500,000. Thus, from a population perspective, the benefit of having the allele outweighs the drawback. Have them speculate how those numbers might change if the sickle cell allele did not exist.

Advanced Students Challenge students to hypothesize how the sickle cell allele became so common among the ancestors of African Americans who lived in central Africa. (After the mutated allele appeared in the population, those individuals who inherited a copy of that allele were more likely to survive malaria and pass the allele on to their children. Individuals without the allele and individuals with both alleles were more likely to die, either from malaria or from sickle cell disease.) Have students construct a Punnett square to show the different phenotypes that can result from various pairings of individuals with the different genotypes for the sickle cell trait.

The Geography of Malaria
Malaria is a potentially fatal disease transmitted by mosquitoes. Its cause is a parasite that lives inside red blood cells. The upper map shows the parts of the world where malaria is common. The lower map shows regions where people have the sickle cell allele.

1. **Analyze Data** What is the relationship between the places where malaria and the sickle cell allele are found?

2. **Infer** In 1805, a Scottish explorer named Mungo Park led an expedition of European geographers to find the source of the Niger River in Africa. The journey began with a party of 45 Europeans. During the expedition, most of these men perished from malaria. Why do you think their native African guides survived?

3. **Form a Hypothesis** As the map shows, the sickle cell allele is not found in African populations that are native to southern Africa. Propose an explanation for this discrepancy.

**Genetic Advantages** Disorders such as sickle cell disease and CF are still common in human populations. In the United States, the sickle cell allele is carried by approximately 1 person in 12 of African ancestry, and the CF allele is carried by roughly 1 person in 25 of European ancestry. Why are these alleles still around if they can be fatal for those who carry them? The answers may surprise you.

Most African Americans today are descended from populations that originally lived in west central Africa, where malaria is common. Malaria is a mosquito-borne infection caused by a parasite that lives inside red blood cells. Individuals with just one copy of the sickle cell allele are generally healthy and are also highly resistant to the parasite. This resistance gives them a great advantage against malaria, which even today claims more than a million lives every year.

More than 1000 years ago, the cities of medieval Europe were ravaged by epidemics of typhoid fever. Typhoid is caused by a bacterium that enters the body through cells in the digestive system. The protein produced by the CF allele helps block the entry of this bacterium. Individuals heterozygous for CF would have had an advantage when living in cities with poor sanitation and polluted water, and—because they also carried a normal allele—these individuals would not have suffered from cystic fibrosis.

**Vocabulary**

**Word Origins** The term malaria was coined in the mid-eighteenth century from the Italian phrase mala aria, meaning “bad air.” It originally referred to the unpleasant odors caused by the release of marsh gases, to which the disease was initially attributed.

**ANSWERS**

1. The areas where malaria is common and the areas where people have the sickle cell allele overlap.

2. They likely carried one allele for the sickle cell trait, so they were healthy and highly resistant to malaria.

3. Malaria is not common in southern Africa, so people who carry the sickle cell allele would not have a reproductive advantage over people who do not carry the sickle cell allele.
Use Visuals

Walk through the two different divisions of meiosis shown in Figure 14–9 to explain how nondisjunction occurs. If necessary, review meiosis so students remember that in meiosis I, homologous chromosomes separate to produce a haploid cell and in meiosis II, sister chromatids separate.

Ask How could Down syndrome result from the type of nondisjunction shown in the figure? (Down syndrome could result if one of the two cells on the left met up with a normal sex cell and the resulting individual had a trisomy for chromosome 21.) Relate Figure 14–9 to Figure 14–1 by having students draw a human karyotype for a person with Down syndrome.

DIFFERENTIATED INSTRUCTION

Content Level Struggling Students Ask students to look at Figure 14–1. Point out that in the trisomy resulting in Down syndrome, the karyotype would show three chromosomes at the 21 position.

Write a paragraph explaining nondisjunction Disorders to see how nondisjunction occurs during meiosis.

Assess and Remediate

EVALUATE UNDERSTANDING

Have students make a Compare/Contrast Table of sickle-cell disease, cystic fibrosis, and Huntington’s disease. Each column should represent a disease, and each row should represent one of the following characteristics: Cause, Effect, and Protein/Amino Acid Affected. Then, have them complete the 14.2 Assessment.

Study Wkbks A/B, Appendix S20, Compare/Contrast Table. Transparencies, GO3.

REMEDIANION SUGGESTION

Content Level Struggling Students If students have trouble with Question 3, have them make a diagram that shows the steps in meiosis I and II when the processes occur normally.

Answers

FIGURE 14–9 The first cell shows metaphase I.

Assessment Answers

1a. It can affect the structure and function of a protein, which may cause a disorder.

1b. Sample answer: People with one CF allele have an advantage of being less likely to contract typhoid fever. This helped them survive and pass the trait to their offspring.

2a. A female with Turner’s syndrome has only one X chromosome, and is sterile. A male with Klinefelter’s syndrome has one or more extra X chromosomes and is usually sterile.

A female with Turner’s syndrome usually inherits only one X chromosome, which interferes with meiosis and usually prevents these individuals from reproducing. Their sex organs do not develop properly at puberty. In males, nondisjunction may cause Klinefelter’s syndrome, resulting from the inheritance of an extra X chromosome, which interferes with meiosis and usually prevents these individuals from reproducing. There have been no reported instances of babies being born without an X chromosome, indicating that this chromosome contains genes that are vital for the survival and development of the embryo.

The most common form of trisomy, involving three copies of an autosome, is Down syndrome, which is often characterized by mild to severe mental retardation and a high frequency of certain birth defects.

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Nondisjunction of the X chromosomes may lead to a disorder known as Turner’s syndrome. A female with Turner’s syndrome usually inherits only one X chromosome. Women with Turner’s syndrome are sterile, which means that they are unable to reproduce. Their sex organs do not develop properly at puberty.

Chromosomal Disorders

What are the effects of errors in meiosis?

Most of the time, the process of meiosis works perfectly and each human gamete gets exactly 23 chromosomes. Every now and then, however, something goes wrong. The most common error in meiosis occurs when homologous chromosomes fail to separate. This mistake is known as nondisjunction, which means “not coming apart.” Figure 14–9 illustrates the process.

If nondisjunction occurs during meiosis, gametes with an abnormal number of chromosomes may result, leading to a disorder of chromosome numbers. For example, if two copies of an autosome chromosome fail to separate during meiosis, an individual may be born with three copies of that chromosome. This condition is known as a trisomy, meaning “three bodies.” The most common form of trisomy, involving three copies of chromosome 21, is Down syndrome, which is often characterized by mild to severe mental retardation and a high frequency of certain birth defects.

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Use Visuals

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Teach

Lead a Discussion

Have students read the feature. Then, explain that all citizens, not just scientists, need to have some knowledge of the human genome because the way data from genetic testing are used can affect everyone. Point out that they may be called upon as voters or jurors to decide on issues or cases related to access of data from genetic testing.

Divide the class into small groups, and have students discuss their viewpoints on regulating genetic data. One member of each group should record the group’s positions. Then, tell each group to devise a set of guidelines for the use of genetic data. Have each group share with the class its guidelines and the reasoning behind them.

Answers

1. Answers will vary. Check that students have investigated state laws regarding genetic discrimination. Sample answer: Proponents argue that genetic testing could lead to treatment of a health condition before symptoms appear. Critics argue that genetic testing could prevent some people from getting health insurance.

2. Accept all reasonable answers. Opinions should include reasonable explanations.

Are Laws Protecting Genetic Privacy Necessary?

The rapid development of new tools and techniques to analyze DNA makes it possible to test for alleles related to thousands of medical conditions. In theory, the results of genetic testing should benefit everyone. Accurate genetic data helps physicians select the proper treatments for patients. It may allow people with genes that place them at risk of certain conditions to minimize those risks.

At issue, however, is individual privacy. Once a test is done, who has access to the data, and how can they use it? Could employers refuse to hire people who might drive up their medical costs? Might insurance companies refuse to renew the policies of individuals with genes for certain disorders? These are not hypothetical questions. In 2005, managers of a professional basketball team asked one of its players to be tested for a gene linked to heart ailments. When he refused, they traded the player to another team. Dr. Francis Collins, director of the National Human Genome Research Institute, worries that “the public is afraid of taking advantage of genetic testing.” Is he correct? Should genetic data be protected by law, or should it be open to public view?

The Viewpoints

Genetic Privacy Does Not Need Legal Protection

Other laws already protect individuals from discrimination on the basis of medical disability. Employers and insurance companies are nonetheless allowed to ask individuals if they smoke, use alcohol, or have a history of medical problems. Having this information allows employers to make intelligent choices about whom to hire. It also helps insurance companies maintain lower rates for their healthiest clients. Free access to genetic data should be a public right.

Genetic Privacy Should Be Protected by Law

Employers or jurors to decide on issues or cases related to genetic testing. "Is he correct? Should genetic data be protected by law, or should it be open to public view?"

Research and Decide

1. Analyze the Viewpoints To make an informed decision, learn more about genetic testing by consulting library or Internet resources. Then, list the key arguments expressed by the proponents and critics of both points of view. Find out if laws preventing genetic discrimination have been proposed or passed in your state.

2. Form an Opinion Should access and use of genetic data be regulated? Weigh both sides of the issue. Who will benefit from the sharing of genetic data? Will anyone suffer? Do some arguments outweigh others? If so, which ones? Explain your answers.

Quick Facts

GENETIC DISCRIMINATION

Genetic discrimination is treating people differently because they are found to have differences in their DNA that increase their risk of developing a certain disease or disorder. For some diseases, such as diabetes or Alzheimer’s disease, a genetic predisposition for a disease does not mean the person will develop the disease, only that the risk is greater. Anti-genetic-discrimination legislation aims to prevent these people from being treated differently than other healthy individuals. The Genetic Information Nondiscrimination Act (GINA) prohibits genetic discrimination by health insurers and employers. However, GINA does not protect against discrimination from insurers of life, disability, and long-term care policies.
THINK ABOUT IT Just a few decades ago, computers were gigantic machines found only in laboratories and universities. Today, many of us carry small, powerful computers to school and work every day. Decades ago, the human genome was unknown. Today, we can see our entire genome on the Internet. How long will it be before having a copy of your own genome is as ordinary as carrying a cellphone in your pocket?

Manipulating DNA

What techniques are used to study human DNA?

Since discovering the genetic code, biologists have dreamed of a time when they could read the DNA sequences in the human genome. For a long time, it seemed impossible. DNA is a huge molecule—even the smallest human chromosome contains nearly 50 million base pairs. Manipulating such large molecules is extremely difficult. In the late 1960s, however, scientists found they could use natural enzymes in DNA analysis. From this discovery came many useful tools. By using tools that cut, separate, and then replicate DNA base by base, scientists can now read the base sequences in DNA from any cell. Such techniques have revolutionized genetic studies of living organisms, including humans.

Cutting DNA Nucleic acids are chemically different from other macromolecules such as proteins and carbohydrates. This difference makes DNA relatively easy to extract from cells and tissues. However, DNA molecules from most organisms are much too large to be analyzed, so they must first be cut into smaller pieces. Many bacteria produce enzymes that do exactly that. Known as restriction enzymes, these highly specific substances cut even the largest DNA molecule into precise pieces, called restriction fragments, that are several hundred bases in length. Of the hundreds of known restriction enzymes, each cuts DNA at a different sequence of nucleotides.

In Your Notebook Make a flowchart that shows the processes scientists use to analyze DNA.

Key Questions

What techniques are used to study human DNA?

What were the goals of the Human Genome Project, and what have we learned so far?

Vocabulary

restriction enzyme

gel electrophoresis

bioinformatics

genomics

Taking Notes

Preview Visuals Before you read, look at Figure 14–10, and write down three questions you have about the figure. As you read, find answers to your questions.

Answers

IN YOUR NOTEBOOK The main processes should include cutting, separating, and reading DNA. Sample answer: DNA molecules are cut into small pieces → DNA pieces are separated by gel electrophoresis → DNA pieces are sequenced.

Build Background

Show students a thick telephone directory and say how many pages are in it. Tell them the number of pages needed to hold the equivalent of the DNA sequence in the human genome is 200,000. Emphasize that every cell in the body contains a copy of this information encoded in the DNA base pairs.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

I, II, III

CONTENT

B.2, C.1.d, C.2.a, C.2.b, C.2.c, F.6, G.1

INQUIRY

A.1.b, A.1.d, A.2.b, A.2.c, A.2.f
LESSON 14.3

**Teach**

**VISUAL SUMMARY**

Use Figure 14–10 to walk students through the steps of manipulating DNA. Provide a visual comparison for each step of the process to help students understand what is happening on the molecular level. Explain that in the first step, restriction enzymes are used like “pinning shears” to cut a DNA molecule so that its tab-shaped cut ends can be matched up exactly with other ends that have been cut by the same “shears.”

In the second step, the DNA fragments are run through gel electrophoresis. Tell them to imagine that the gel is like a yard of grass and the DNA fragments are like leaves of different sizes. When a leaf blower blows the leaves across the grass, the smaller, lighter-weight ones are able to tumble faster and farther than the larger, heavier leaves.

**Ask** In the yard analogy, what does the wind from the leaf blower represent? (the electric current that draws the DNA strands across the gel)

Encourage students to come up with a third visual comparison or expand upon the first two for the final step of manipulating DNA.

**DIFFERENTIATED INSTRUCTION**

**ELL** Less Proficient Readers Have students make their own labeled drawings of the steps involved in manipulating DNA. Ask them to write in their own words what is happening in each step.

**Focus On ELL:** Extend Language

**ALL SPEAKERS** Give students practice using gene sequencing terminology by providing Cloze Prompts. Distribute a modified paragraph that describes the steps shown in Figure 14–10 but leaves some strategic words blank. An example is “The enzyme that copies DNA is _______.” (DNA polymerase) Provide a word bank for beginning speakers. For intermediate speakers, omit the word bank. Advanced and advanced high speakers can make up their own sentences and then switch with another student to fill in the blanks.

**Study Wkbks A/B, Appendix S2, Cloze Prompts.**

**UbD** Check for Understanding

**HAND SIGNALS**

Present students with the following questions and ask them to show a thumbs-up sign if they can answer the question, a thumbs-down sign if they definitely cannot, or a waving-hand sign if they are not sure.

- Why are restriction enzymes used to cut DNA?
- How do DNA fragments separate from each other in an electrophoresis gel?
- Why is DNA polymerase used in sequencing DNA?

**ADJUST INSTRUCTION**

If students showed a thumbs-down or waving-hand sign for any questions, pair students and have them reread the text on this and the previous page and study Figure 14–10. Give student pairs a few minutes to discuss the answers.

**Seperating DNA** Once DNA has been cut by restriction enzymes, scientists can use a technique known as gel electrophoresis to separate and analyze the differently sized fragments. Figure 14–10 illustrates this simple, yet effective, method. A mixture of DNA fragments is placed at one end of a porous gel. When an electric voltage is applied to the gel, DNA molecules—which are negatively charged—move toward the positive end of the gel. The smaller the DNA fragment, the faster and farther it moves. The result is a pattern of bands based on fragment size. Specific stains that bind to DNA make these bands visible. Researchers can then remove individual restriction fragments from the gel and study them further.

**Reading DNA** After the DNA fragments have been separated, researchers use a clever chemical “trick” to read, or sequence, them. The single-stranded DNA fragments are placed in a test tube containing DNA polymerase—the enzyme that copies DNA—along with the four nucleotide bases, A, T, G, and C. As the enzyme goes to work, it uses the unknown strand as a template to make one new DNA strand after another. The tricky part is that researchers also add a small number of bases that have a chemical dye attached. Each time a dye-labeled base is added to a new DNA strand, the synthesis of that strand stops. When DNA synthesis is completed, the result is a series of color-coded DNA fragments of different lengths. Researchers can then separate these fragments, often by gel electrophoresis. The order of colored bands on the gel tells the exact sequence of bases in the DNA. The entire process can be automated and controlled by computers, so that DNA sequencing machines can read thousands of bases in a matter of seconds.
**Reading DNA**

A small proportion of dye-labeled nucleotides are used to make a complementary DNA strand. Each time a labeled nucleotide is added to the strand, DNA replication stops. Because each base was labeled with a different color, the result is color-coded DNA fragments of different lengths. When gel electrophoresis is used to separate the fragments, scientists can “read” the DNA sequence directly from the gel.

**Quick Lab**

**Guided Inquiry**

**Modeling Restriction Enzymes**

1. Write a 50-base, double-stranded DNA sequence using the bases A, C, G, and T in random order. Include each sequence shown below at least once in the sequence you write.

2. Make three copies of your double-stranded sequence on three different-colored strips of paper.

3. Use the drawings below to see how the restriction enzyme EcoRI would cut your DNA sequence. Use scissors to cut one copy of the sequence as EcoRI would.

4. Use the procedure in Step 3 to cut apart another copy of your sequence as the restriction enzyme BamI would. Then, cut the third copy as the restriction enzyme HaeIII would.

5. Tape the single-stranded end of one of your DNA fragments to a complementary, single-stranded end of a classmate’s fragment. This will form a single, double-stranded DNA molecule.

**Analyze and Conclude**

1. **Observe** Which restriction enzyme produced the most pieces? The fewest pieces?

2. **Evaluate** How well did your model represent the actual process of using restriction enzymes to cut DNA? (Hint: Contrast the length of your model DNA sequence to the actual length of a DNA molecule.)

**DIFFERENTIATED INSTRUCTION**

**Special Needs** Check for understanding by asking questions such as “Why are four different colors used?” (There are four different bases.) and “Why do the fragments line up from bottom to top in size?” (The smaller pieces are moving faster toward the positive end of the gel.) Then, have students model the sequencing of DNA using crafts materials, such as yarn, beads, and color construction paper.

**Advanced Students** Challenge students to explain how a power source is set up to create a circuit with a current that moves the DNA molecules across the gel during the sequencing process. (The power source has positive and negative electrodes connected to either end of the gel. The positive electrode is attached on the end away from the wells so that the negatively charged DNA moves toward it.) Have them make a sketch of a power setup with labels of all charges and arrows to indicate how the fragments move.

**ANALYZE AND CONCLUDE**

1. Answers will vary.

2. Sample answer: The model well represents the action of restriction enzymes and the “sticky ends” they create, but the number of fragments produced is much smaller than would be produced by a DNA molecule.
LESSON 14.3

Use Models

Review the steps in shotgun sequencing shown in Figure 14–11. Explain that the term shotgun sequencing is an analogy to the random pattern that shot makes when fired from a shotgun. Then, model shotgun sequencing with the following activity. Tell students that they will be identifying the sequence of an unknown strand of DNA using fragments of identical strands. The unknown strand has 28 base pairs, and there are four known markers found in the following order on the strand: GTAC, TTT, CCCC, and TCTG.

Have students copy the following six fragments of the DNA strand onto separate strips of paper: TACCCCAA, TACATTT, ATTACCCCA, CAATTCTGCGG, GGTAACA, TCTGCCGGG. Then, tell them to work together to match up the markers using shotgun sequencing to determine the sequence of the unknown DNA strand. (The solution: GGTAACCTTACCCCAATCTGCCCCGGG)

Ask What problem did scientists solve by using shotgun sequencing? (Sample answer: The human genome is so large that sequencing only a few hundred nucleotides at a time would take a very long time. Shotgun sequencing shortened the task of sequencing all three billion base pairs of DNA.)

DIFFERENTIATED INSTRUCTION

EL Special Needs Model shotgun sequencing as above, only use strips of paper with colored dots or stickers, pieced fabric of differing textures or color, or lengths of colored yarn.

ELL English Language Learners Have students incorporate the information about sequencing base pairs and identifying genes into a Main Ideas and Details Chart. Encourage them to use their own words. Beginning and intermediate speakers may use single words or short phrases. (Sample answer: Main Idea—shotgun sequencing; Details—cut DNA; sort DNA, etc.) Advanced and advanced high speakers should use complete sentences.

Study Wkbks A/B, Appendix S28, Main Ideas and Details Chart, Transparencies, GO13.

The Human Genome Project

What were the goals of the Human Genome Project, and what have we learned so far?

In 1990, the United States, along with several other countries, launched the Human Genome Project. The Human Genome Project was a 13-year, international effort with the main goals of sequencing all 3 billion base pairs of human DNA and identifying all human genes. Other important goals included sequencing the genomes of model organisms to interpret human DNA, developing technology to support the research, exploring gene functions, studying human variation, and training future scientists.

DNA sequencing was at the center of the Human Genome Project. However, the basic sequencing method you saw earlier can only analyze a few hundred nucleotides at a time. How, then, can the huge amount of DNA in the human genome be sequenced quickly? First, researchers must break up the entire genome into manageable pieces. By determining the base sequences in widely separated regions of a DNA strand, they can use the regions as markers, not unlike the mile markers along a road that is thousands of miles long. The markers make it possible for researchers to locate and return to specific locations in the DNA.

Sequencing and Identifying Genes Once researchers have marked the DNA strands, they can use the technique of “shotgun sequencing.” This rapid sequencing method involves cutting DNA into random fragments, then determining the base sequence in each fragment. Computer programs take the sequencing data, find areas of overlap between fragments, and put the fragments together by linking the overlapping areas. The computers then align these fragments relative to the known markers on each chromosome, as shown in Figure 14–11. The entire process is like putting a jigsaw puzzle together, but instead of matching shapes, the computer matches DNA base sequences.

Reading the DNA sequence of a genome is not the same as understanding it. Much of today’s research explores the vast amount of data from the Human Genome Project to look for genes and the DNA sequences that control them. By locating sequences known to be promoters—binding sites for RNA polymerase—scientists can identify many genes. Shortly after a promoter, there is usually an area called an open reading frame, which is a sequence of DNA bases that will produce an mRNA sequence. Other sites that help to identify genes are the sequences that separate introns from exons, and stop codons located at the ends of open reading frames. Figure 14–12 shows these sites on a typical gene.
Comparing Sequences

If you were to compare the genomes of two unrelated individuals, you would find that most—but not all—of their DNA matches base-for-base with each other. On average, one base in 1200 will not match between two individuals. Biologists call these single base differences SNPs (pronounced “snips”), which stands for single nucleotide polymorphisms. Researchers have discovered that certain sets of closely linked SNPs occur together time and time again. These collections of linked SNPs are called haplotypes—short for haploid genotypes. To locate and identify as many haplotypes in the human population as possible, the International HapMap Project began in 2002. The aim of the project is to give scientists a rapid way to identify haplotypes associated with various diseases and conditions and to pave the way to more effective life-saving medical care in the future.

Sharing Data

The Human Genome Project was completed in 2003. Copies of the human genome DNA sequence, and those of many other organisms, are now freely available on the Internet. Online computer access enables researchers and students to browse through databases of human DNA and study its sequence. More data from the human genome, and the genomes of other organisms, are added to these databases every day.

One of the key research areas of the Human Genome Project was a new field of study called bioinformatics. The root word, informatics, refers to the creation, development, and operation of databases and other computing tools to collect, organize, and interpret data. The prefix bio—refers to life sciences—specifically, molecular biology. Assembling the bits and pieces of the human genome would have been impossible without sophisticated computer programs that could recognize overlapping sequences and place them in the proper order, or immense databases where such information could be stored and retrieved. Without the tools of bioinformatics shown in Figure 14–13, the wealth of information gleaned from the Human Genome Project would hardly be useful. Bioinformatics also launched a more specialized field of study known as genomics—the study of whole genomes, including genes and their functions.

Hypotheses

Students can go online to Biology.com to gather information to infer that the sickle cell mutation affects the formation of the protein hemoglobin.

How Science Works

MORE ABOUT HAPMAPS

The HapMap Project is of particular interest to scientists in medical fields because haplotypes—as opposed to single SNPs—are more likely to be associated with diseases such as cancer, heart disease, and diabetes, which involve multiple genes. Searching for key disease-related haplotypes would be currently less expensive and less time-consuming than comparing the complete genetic sequences of healthy individuals with those of individuals who have a particular disease. Scientists hope to use the HapMap not only to identify regions of the human genome that are associated with diseases but also to study susceptibility to infection and sensitivity to environmental factors, drugs, and vaccines.

Build Reading Skills

Help students understand the content under the green heading, The Human Genome Project, by summarizing the main ideas and supporting details. Model how to do this using the paragraph with the blue heading, Comparing Sequences. Explain that they should first carefully read the paragraph and identify the main idea in their own words—for example, “When comparing two unrelated people’s genomes, small differences in the sequence can tell scientists a lot about the individuals.”

Next, they should identify important supporting details—for example, “SNPs are single base differences between two unrelated individuals,” “A haplotype is a collection of linked SNPs,” and “The HapMap project helps scientists identify haplotypes associated with various diseases.” Direct students to repeat this process for each paragraph in the section. Remind them to focus on the most important concepts, omitting minor details and examples.

DIFFERENTIATED INSTRUCTION

Struggling Students

Have students work in pairs to create an outline that summarizes the concepts under the green heading, The Human Genome Project. Explain that a good way to start an outline is to use the headings themselves as the framework. Tell students that they can also use Key Concept statements, highlighted vocabulary terms, and figure titles as guides for determining the important concepts. Have them refer back to their outlines when completing the lesson assessment.

If students need help answering the question, have them reread Comparing Sequences and identify the characteristics of a haplotype. Then, guide them to use this information to infer that the sickle cell mutation affects the formation of the protein hemoglobin. Students can go online to Biology.com to gather their evidence.
LESSON 14.3

Lead a Discussion

Have students identify characteristics scientists discovered about the human genome as you list them on the board.

Ask: What information did scientists find surprising about the human genome? (Chromosomes have large regions that contain very few genes.)

Ask: What inference can be made about the similarities between coded proteins in humans and other organisms? (Humans and other organisms have a common evolutionary origin.)

Finally, have students discuss how scientists might use their knowledge of the location of sequences for diseases and disorders.

DIFFERENTIATED INSTRUCTION

Advanced Students

Have students search the Internet and scientific journals for the latest findings on a disease or disorder associated with gene sequences identified through the Human Genome Project. Have students present their findings to the class by giving an oral report.

Address Misconceptions

Single Gene vs. Multifactorial Diseases

Students may think that inheriting DNA sequences for any disease means the person will definitely develop the disease. Review how single gene disorders, such as CF, are passed through families in such a way that offspring who inherit the mutated gene will develop the disease. Highlight the fact that, in such cases, environment does not affect whether the person develops disease. Explain that most genetic diseases, such as heart disease and most cancers, are multifactorial—a combination of factors determines whether disease will develop. A person who inherits these genes is at higher risk of developing the disease, but may never actually develop it, due to environmental and behavioral factors. For example, a person who inherits genes for heart disease can greatly decrease his or her risk of developing the disease by avoiding tobacco smoke, maintaining a healthy weight, and eating a healthy diet.

Answers

FIGURE 14–15 Sample answer: I could use an Internet search engine to search for articles by entering the key phrase “size comparison of genomes.” To make sure that the information was current, I could check the dates of the articles that result from the search.

What We Have Learned

In June 2000, scientists announced that a working copy of the human genome was complete. The first details appeared in the February 2001 issues of the journals Nature and Science. The full reference sequence was completed in April 2003, marking the end of the Human Genome Project—two years ahead of the original schedule. Coincidentally, that was also the fiftieth anniversary of Watson and Crick’s publication of DNA structure that launched the era of molecular biology!

Besides finding that the human genome in its haploid form contains three billion nucleotide bases, the Human Genome Project uncovered a wealth of interesting, and sometimes surprising, information. For instance, only about 2 percent of our genome encodes instructions for the synthesis of proteins, and many chromosomes contain large areas with very few genes. As much as half of our genome is made up of DNA sequences from viruses and other genetic elements within human chromosomes. During the project, investigators completed the genomes of several other organisms, including unicellular ones. They found that more than 40 percent of the proteins coded for by our genome have strong similarity to proteins in many of those organisms, including fruit flies, worms, and even yeast. Figure 14–15 compares the human genome with these and other model organisms.

By any standard, the Human Genome Project has been a great scientific success. The Human Genome Project pinpointed genes and associated particular sequences in those genes with numerous diseases and disorders. It also identified about three million locations where single-base DNA differences occur in humans. This information may help us find DNA sequences associated with diabetes, cancer, and other health problems. The Human Genome Project also transferred important new technologies to the private sector, including agriculture and medicine. By doing so, the project catalyzed the U.S. biotechnology industry and fostered the development of new medical applications.

Quick Facts

GENES ASSOCIATED WITH OBESITY

Obesity, a major health issue that, in recent decades, has reached epidemic proportions in many populations, is associated with more than 400 genes to date. While the condition has a strong association with genes, it is a multifactorial trait resulting also from environmental and lifestyle influences. Researchers in Canada have developed the Human Obesity Gene Map, an online database that contains information on genes associated with obesity. By studying these genes and their interactions with the environment, researchers hope to better address the obesity problem through prevention and intervention.
New Questions  Throughout its duration, the Human Genome Project worked to identify and address ethical, legal, and social issues surrounding the availability of human genome data and its powerful new technologies. The issues, including privacy, fairness in the use of and access to genomic information, medical issues, and commercialization, are complex. For example, who owns and controls genetic information? Is genetic privacy different from medical privacy? Who should have access to personal genetic information, and how will it be used? Right now, these questions are hypothetical, but they may not be for long. In May 2008, President George Bush signed into law the Genetic Information Nondiscrimination Act, which prohibits U.S. insurance companies and employers from discriminating on the basis of information derived from genetic tests. Other protective laws may soon follow.

What’s Next? Many more sequencing projects are underway, helped along by powerful new technologies. You can expect an ever-growing database of information from microbial, animal, and plant genomes in the years ahead. Each of these will have its own mysteries to be explored, not to mention the fact that we still don’t fully understand the functions of as many as 50 percent of the human genes thus far discovered.

The 1000 Genomes Project, launched in 2008, will study the genomes of 1000 people in an effort to produce a detailed catalogue of human variation. Data from the project will be used in future studies of development and disease, and the information may hold the key to successful research on new drugs and therapies to save human lives and preserve health.

Perhaps the most important challenge that lies ahead is to understand how all the “parts” of cells—genes, proteins, and many other molecules—work together to create complex living organisms. Future efforts may provide a deeper understanding of the molecular processes underlying life and may influence how we view our own place in the global ecosystem.

Assess and Remediate

EVALUATE UNDERSTANDING

Have students verbally summarize the information displayed in each figure in the lesson. Then, have them complete the 14.3 Assessment.

REMEDIATION SUGGESTION

If students have trouble with Question 2b, review with them the last paragraph in What We Have Learned, and brainstorm specific examples of how gene technology might be used in the future. Then, have them reread New Questions and suggest answers to each question.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

1a. They look for promoters, open reading frames, the sequences that separate introns from exons, and stop codons.

1b. In a jigsaw puzzle, shapes are matched to recreate the puzzle. In shotgun sequencing, DNA base sequences are matched to recreate the genome.

2a. The Human Genome Project is an international effort to sequence all 3 billion base pairs of human DNA and to identify all human genes.

2b. Sample answer: The project might benefit humankind by helping scientists learn about the causes of genetic disorders. Potential problems include deciding who owns and controls genetic information.

3. Answers will vary, but opinions should be fully developed and supported by examples. Sample answer: A child’s inherited traits should be altered if those traits relate to disease. Traits should not be altered to change a child’s appearance.

Assessment Answers

1a. They look for promoters, open reading frames, the sequences that separate introns from exons, and stop codons.

1b. In a jigsaw puzzle, shapes are matched to recreate the puzzle. In shotgun sequencing, DNA base sequences are matched to recreate the genome.

2a. The Human Genome Project is an international effort to sequence all 3 billion base pairs of human DNA and to identify all human genes.

2b. Sample answer: The project might benefit humankind by helping scientists learn about the causes of genetic disorders. Potential problems include deciding who owns and controls genetic information.

3. Answers will vary, but opinions should be fully developed and supported by examples. Sample answer: A child’s inherited traits should be altered if those traits relate to disease. Traits should not be altered to change a child’s appearance.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Using DNA to Identify Human Remains described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 346.

Background Questions

a. A pedigree is a chart that is used to analyze the pattern of inheritance of a trait across several generations.

b. In a pedigree, a circle represents a female and a square represents a male.

c. Sample answer: The sequence of nucleotides in mtDNA remains constant over many generations. (All the daughter cells must have identical mtDNA.)

Pre-Lab Questions

1. Infer The tsar and tsarina had five children. Did all seven family members have the same mtDNA? Give a reason for your answer.

2. Predict To confirm that bones belonged to the tsar’s children, which living relative would be more useful—a relative of the tsar or a relative of the tsarina? Why?

3. Infer If two people have the same mtDNA, what can you infer about their biological relationship?

The Romanovs ruled Russia for 300 years until the Bolshevik Revolution of 1918 resulted in the execution of Tsar Nicholas II and his family.

Visit Chapter 14 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video The Untamed Science crew identifies the chromosomes that carry genes for colorblindness.

Art in Motion View a short animation that explains nondisjunction.

Art Review Review your understanding of karyotypes with this drag-and-drop activity.

InterActive Art Learn all about pedigrees and how to make them with this animation.

Data Analysis Analyze the connection between type O blood and an increased susceptibility to cholera.

Tutor Tube Why do traits sometimes “skip a generation”? Tune in to the tutor to find out.

Pre-Lab Answers

BACKGROUND QUESTIONS

a. A pedigree is a chart that is used to analyze the pattern of inheritance of a trait across several generations.

b. In a pedigree, a circle represents a female and a square represents a male.

c. Sample answer: The sequence of nucleotides in mtDNA remains constant over many generations. (All the daughter cells must have identical mtDNA.)

PRE-LAB QUESTIONS

1. The tsarina and the children had the same mtDNA because the children inherited their mtDNA from the tsarina. The tsar had different mtDNA, which he inherited from his mother.

2. A living relative of the tsarina would be more useful because that relative would have the same mtDNA as the children.

3. Sample answer: The two people have a common ancestor on the maternal side of their family trees.
Humans have 23 pairs of chromosomes, including one pair of sex chromosomes, that follow the same patterns of Mendelian inheritance as do other organisms. Scientists study human heredity using karyotypes, pedigrees, and Punnett squares, but they also use the tools of molecular biology and bioinformatics to study DNA and gene expression. The Human Genome Project has revolutionized the study of human heredity.

14.1 Human Chromosomes

- A karyotype shows the complete diploid set of chromosomes grouped together in pairs, arranged in order of decreasing size.
- Human genes follow the same Mendelian patterns of inheritance as the genes of other organisms. Many human traits follow a pattern of simple dominance. The alleles for other human genes display codominant inheritance. Because the X and Y chromosomes determine sex, the genes located on them show a pattern of inheritance called sex-linkage.
- The information gained from pedigree analysis makes it possible to determine the nature of genes and alleles associated with inherited human traits.

14.2 Human Genetic Disorders

- Changes in a gene’s DNA sequence can change proteins by altering their amino acid sequences, which may directly affect one’s phenotype.
- If nondisjunction occurs during meiosis, gametes with an abnormal number of chromosomes may result, leading to a disorder of chromosome numbers.

14.3 Studying the Human Genome

- By using tools that cut, separate, and then replicate DNA base by base, scientists can now read the base sequences in DNA from any cell.
- The Human Genome Project was a 13-year, international effort with the main goals of sequencing all 3 billion base pairs of human DNA and identifying all human genes.
- The Human Genome Project pinpointed genes and associated particular sequences in those genes with numerous diseases and disorders. It also identified about three million locations where single-base DNA differences occur in humans.

THINK VISUALLY

Create a concept map using the following terms:

Answers

THINK VISUALLY

Students’ concept maps should show that inheritable disorders can be caused by nondisjunction of autosomes (in the case of Down syndrome) or sex chromosomes (in the case of Turner’s syndrome and Klinefelter’s syndrome).

TRANSFER TASK

Tell students that several companies market genetic tests directly to consumers, who send in a saliva sample to be tested for particular genes. Some tests tell whether a person is at higher risk for a disease, such as Alzheimer's, heart disease, and some cancers. As a class, discuss the following questions:

- Would you want to know your risk of certain diseases? If so, which ones and why? If not, why not?
- If you choose to know, what would you do, if anything, with the data? For example, would you change your lifestyle?

- Would you share your data with anyone, for example, your doctor or a prospective marriage partner? Explain.

After the discussion, have individuals write a fictional letter to a friend or family member persuading him or her to use or avoid using a mail-order genetics test for a certain disease. In their letters, they should support their arguments with information learned from the chapter.
Lesson 14.1

UNDERSTAND KEY CONCEPTS
1. b  2. a  3. b
4. The sex chromosomes, X and Y, determine an individual's sex; the remaining 22 pairs of chromosomes are autosomal.
5. No, the \( I^A \) and \( I^B \) alleles are codominant. When both alleles are present in an individual, that person has blood type AB.

THINK CRITICALLY
6. The father's genotype could be \( X^C Y \) or \( X^C Y \) because he contributes to his sons only the Y chromosome, which does not determine colorblindness. The mother's genotype must be \( X^C X^C \) (a carrier of the gene for colorblindness) or \( X^C X^c \) (colorblind and homozygous for the gene for colorblindness).
7. Answers will vary but may include a cross between a diseased female and a normal male. If the gene is sex-linked, the disease will appear only in male offspring.

Lesson 14.2

UNDERSTAND KEY CONCEPTS
8. d  9. b  10. d
11. It is the karyotype of a person with Down syndrome, because it has three copies of chromosome 21.
12. A chromosomal disorder is a disorder caused by nondisjunction during meiosis, resulting in gametes with an abnormal number of chromosomes.
13. A female with Turner's syndrome has only one X chromosome and is sterile. A male with Klinefelter's syndrome has one or more extra X chromosomes and is usually sterile.

THINK CRITICALLY
14. No, cystic fibrosis is caused by a gene mutation. Karyotypes can detect abnormalities only in chromosome number.
15. The incidence of Down syndrome increases with the age of the mother.
15. Interpret Graphs  What can you infer about the relationship between the age of the mother and the incidence of Down syndrome?

14.3  Studying the Human Genome

Understand Key Concepts

16. The human genome consists of approximately how many DNA base pairs?
   a. 30,000   b. 3,000,000   c. 300,000,000   d. 3,000,000,000

17. The fraction of the human genome that actually codes for proteins is about
   a. 2%     b. 20%     c. 98%     d. 100%

18. Cutting DNA into small pieces that can be sequenced is accomplished by
   a. restriction enzymes
   b. DNA polymerase
   c. gel electrophoresis
   d. RNA polymerase

19. If you sequence short pieces of DNA and then use a computer to find overlapping sequences that map to a much longer DNA fragment, you are using
   a. genomics
   b. hapmaps
   c. shotgun sequencing
   d. open reading frame analysis

20. Describe the tools and processes that scientists use to manipulate human DNA.

21. Explain why restriction enzymes are useful tools in sequencing DNA.

Lesson 14.3  UNDERSTAND KEY CONCEPTS

16. d  17. a  18. a  19. c

20. Answers should include descriptions of restriction enzymes, gel electrophoresis, and the use of colored labels in sequencing DNA.

21. Restriction enzymes can cut DNA into short fragments at predictable locations. The short fragments can be more easily sequenced.

After students read through the Chapter Mystery, ask them to work in pairs to construct a pedigree to illustrate how sickle cell disease and the trait have been passed in Ava's family. Tell students to use the pedigree to infer each individual’s possible genotype and label it using $S$ for the normal allele and $s$ for the defective allele. Make sure students have drawn the correct pedigree by asking the following questions.

Ask What is the genotype of Ava’s grandmother? Explain. (ss because she has the disease)

Ask What is the genotype of Ava’s grandfather? Explain. (Ss because neither he nor Ava’s father have the disease; Ava’s father must have inherited a normal allele from his father, and Ava’s uncle must have inherited a recessive allele from him.)

Ask What are the possible genotypes for Ava’s mother? (SS and Ss)

CHAPTER MYSTERY ANSWERS

1. Students should recognize that the sickle cell alleles are inherited in a dominant-recessive pattern. Sickle cell disease is autosomal (not X-linked) recessive. A person must inherit two recessive alleles for sickle cell disease to develop.

2. Ava’s grandfather must be heterozygous for the trait, because Ava’s grandmother is homozygous recessive but Ava’s father does not have the disease. Her father had to have received one normal allele from her grandfather. Ava has 50% chance of being a carrier of the sickle cell trait.

3. Sample answer: Protein amino-acid sequencing of beta-globin or DNA analysis of the gene that codes for that protein would show whether Ava is a carrier of the defective allele, because the allele that causes sickle cell disease is known.

4. The fragments from Uncle Eli will be longer than some of his brother’s, because the enzyme will not recognize (and therefore will not cut) the DNA that contains the sickle cell mutation.

5. Students should recognize that the test could be performed using restriction enzymes to cut DNA at specific sites and include gel electrophoresis and DNA sequencing as techniques to analyze the results.

Suggest students follow the Untamed Science crew in What Color Are My Genes? to find out how colorblindness is inherited.
22. An SNP is a place in the human genome where a single DNA base does not match between two unrelated individuals.

23. Bioinformatics is the creation, development, and operation of databases and other tools to collect, organize, and interpret biological data.

THINK CRITICALLY

24. It is likely that protein coding genes are located in open reading frames that follow promoter sequences.

25. DNA is negatively charged.

26. BamHI, HindIII, and EcoRI are the three restriction enzymes that produce sticky ends. All the restriction enzyme recognition sites are sequences that read the same in both directions.

Connecting Concepts

USE SCIENCE GRAPHICS

27. In fruit flies, maleness and femaleness are determined by the number of X chromosomes (one for male, two for female). In humans, maleness requires a Y chromosome.

28. Genes on the Y chromosome are not necessary for survival.

WRITE ABOUT SCIENCE

29. Students’ explanations should include a description of the inheritance of a sex-linked gene, an explanation as to why it is more common in males, and at least one example of genotypes in two parents that would result in a child with colorblindness. Females must receive both defective copies of the allele to be colorblind, while males must receive just one copy (from their mothers) to be colorblind.

30. Students’ explanations should include a description of nondisjunction (how chromosomes fail to separate in meiosis) and the combinations of chromosomes in gametes that result in each of the disorders. Down syndrome is trisomy 21, Turner’s syndrome is a female having only one X chromosome, and Klinefelter’s syndrome is a male having more than one X chromosome.

Use Science Graphics

Use the data table to answer questions 27 and 28.

<table>
<thead>
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<th>Sex Chromosomes</th>
<th>Fruit Fly Phenotype</th>
<th>Human Phenotype</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>XXY</td>
<td>Female</td>
<td>Male</td>
</tr>
</tbody>
</table>

27. **Interpret Tables** What differs in the sex-determining mechanism of the two organisms?

28. **Draw Conclusions** What can you logically conclude about the genes on the sex chromosomes of fruit flies and humans?

Write about Science

29. **Explanation** Write a paragraph that tells how colorblindness is inherited. Describe the condition and explain why it is much more common in males. (Hint: Begin your paragraph with a topic sentence that expresses the paragraph’s main idea.)

30. **Assess the Big Idea** Explain the relationship between meiosis and Down syndrome, Turner’s syndrome, and Klinefelter’s syndrome.

31. **Interpret Diagrams** Which mothers are definite carriers of the gene?

32. **Apply Concepts** Why did the sons of Person 3 not inherit the trait?

33. **Apply Concepts** How could Person 12 have hemophilia if neither of his parents had hemophilia?
Multiple Choice

1. Which of the following disorders can be observed in a human karyotype?
   A colorblindness
   B trisomy 21
   C cystic fibrosis
   D sickle cell disease

2. Which of the following disorders is a direct result of nondisjunction?
   A sickle cell disease
   B Turner’s syndrome
   C Huntington’s disease
   D cystic fibrosis

3. A woman is homozygous for A⁻ blood type. A man has AB⁻ blood type. What is the probability that the couple’s child will have type B⁻ blood?
   A 0%
   B 50%
   C 75%
   D 100%

4. Cystic fibrosis is a genetic disorder caused by a
   A single base substitution in the gene for hemoglobin.
   B deletion of an amino acid from a chloride channel protein.
   C defective gene found on the X chromosome.
   D trisomy of chromosome 21.

5. The technique used to separate DNA strands of different lengths is
   A gel electrophoresis.
   B shotgun sequencing.
   C restriction enzyme digestion.
   D bioinformatics.

6. The study of whole genomes, including genes and their functions, is called
   A bioinformatics.
   B information science.
   C life science.
   D genomics.

7. DNA can be cut into shorter sequences by proteins known as
   A haplotypes.
   B restriction enzymes.
   C restriction fragments.
   D restriction enzymes.

8. Which pattern of inheritance is consistent with the pedigree?
   A sex-linked inheritance
   B complete dominance
   C codominance
   D multiple alleles

9. What are the probable genotypes of the student’s parents?
   A Mother—Ww; Father—ww
   B Mother—ww; Father—ww
   C Mother—WW; Father—Ww
   D Mother—Ww; Father—Ww

Open-Ended Response

10. Explain how the gene for sickle cell disease, which is a harmful gene when it is homozygous, can be beneficial when it is heterozygous.

It is harmful in homozygous individuals because all of their hemoglobin has the defective form of the protein and the resulting defective red blood cells do not function normally, causing clots that can damage tissues. It is beneficial in heterozygous individuals because they are generally healthy and being carriers of the trait makes them resistant to the malaria parasite.
By cloning cells and modifying genes, scientists in Korea have developed cats that glow bright red in the dark. The cloned Turkish Angola on the left has a fluorescent protein in its skin cells. The protein gives off a red glow when exposed to ultraviolet light. The ordinary Turkish Angola on the right lacks the red fluorescent protein, so it appears green under ultraviolet light.
In the summer of 1998, an elderly Indiana woman was brutally assaulted. In the predawn darkness, she didn’t get a look at her assailant’s face. At first light, police found a man only a few blocks from the victim’s house. He was unconscious, his clothing was stained with blood, and there were scratches on his forearms. The man claimed that he had passed out following a drunken brawl. He couldn’t remember what had happened afterward. The blood type of the stains on his clothing matched the victim’s blood type. The police thought they had their man. Hours later, the police knew they had the wrong suspect. They resumed their search for the real attacker, who was subsequently caught, tried, and convicted. As you read this chapter, look for clues to help you determine how the police knew they had the wrong suspect. Then, solve the mystery.

Never Stop Exploring Your World. Finding the solution to the case of mistaken identity is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.
15.1 Selective Breeding

Key Questions

- What is selective breeding used for?
- How do people increase genetic variation?

Vocabulary

selective breeding
hybridization
inbreeding
biotechnology

Taking Notes

Outline Before you read this lesson, start an outline. Use the green headings in the lesson as first-level entries. Use the blue headings as second-level entries, leaving space after each entry. As you read, summarize the key ideas below your entries.

Selective Breeding

What is selective breeding used for?

Visit a dog show, and what do you see? Striking contrasts are everywhere—from a tiny Chihuahua to a massive Great Dane, from the short coat of a Labrador retriever to the curly fur of a poodle, from the long muzzle of a wolfhound to the pug nose of a bulldog. The differences among breeds of dogs, like the ones in Figure 15–1, are so great that someone might think they are different species. They’re not, of course, but where did these obvious differences come from?

The answer is that we did it. Humans have kept and bred dogs for thousands of years, always looking to produce animals that are better hunters, better retrievers, or better companions. We’ve done so by selective breeding, allowing only those animals with wanted characteristics to produce the next generation. Humans use selective breeding, which takes advantage of naturally occurring genetic variation, to pass wanted traits on to the next generation of organisms.

Think About It

You’ve enjoyed popcorn at the movies, you’ve probably made it at home, and you’ve certainly seen it in stores. Where does it come from? Would you be surprised to learn that popcorn is one of the earliest examples of human efforts to select and improve living organisms for our benefit? Corn as we know it was domesticated at least 6000 years ago by Native Americans living in Mexico. A tiny kernel of popped corn found in a cave is New Mexico is more than 5000 years old!
For thousands of years, we’ve produced new varieties of cultivated plants and nearly all domestic animals—including horses, cats, and cows—by selectively breeding for particular traits. Long before Europeans came to the New World, Native Americans had selectively bred teosinte (tee oh sин tee), a wild grass native to central Mexico, to produce corn, a far more productive and nutritious plant. Figure 15–2 shows both plants. Corn is now one of the world’s most important crops. There are two common methods of selective breeding—hybridization and inbreeding.

**Hybridization** American botanist Luther Burbank may have been the greatest selective breeder of all time. During his lifetime (1849–1926), he developed more than 800 varieties of plants. As one of his tools, Burbank used hybridization, crossing dissimilar individuals to bring together the best of both organisms. Hybrids—the individuals produced by such crosses—are often hardier than either of the parents. Many of Burbank’s hybrid crosses combined the disease resistance of one plant with the food-producing capacity of another. The result was a new line of plants that had the traits farmers needed to increase food production. Figure 15–3 shows a type of peach developed using Burbank’s methods.

**Inbreeding** To maintain desirable characteristics in a line of organisms, breeders often use a technique known as inbreeding. Inbreeding is the continued breeding of individuals with similar characteristics. The many breeds of dogs—from beagles to poodles—are maintained using this practice. Inbreeding helps ensure that the characteristics that make each breed unique are preserved. Although inbreeding is useful in preserving certain traits, it can be risky. Most of the members of a breed are genetically similar, which increases the chance that a cross between two individuals will bring together two recessive alleles for a genetic defect.

In Your Notebook Compare and contrast hybridization and inbreeding.

### Increasing Variation

**How do people increase genetic variation?**

Selective breeding would be nearly impossible without the wide variation found in natural populations of plants and animals. But sometimes breeders want more variation than exists in nature.

**Breeders can increase the genetic variation in a population by introducing mutations, which are the ultimate source of biological diversity.**

When scientists manipulate the genetic makeup of an organism, they are using biotechnology. Biotechnology is the application of a technological process, invention, or method to living organisms. Selective breeding is one form of biotechnology important in agriculture and medicine, but there are many others.
### Bacterial Mutations
Mutations—heritable changes in DNA—occur spontaneously, but breeders can increase the mutation rate of an organism by using radiation or chemicals. Many mutations are harmful to the organism. With luck and perseverance, however, breeders can often produce a few mutants—individuals with mutations—with useful characteristics that are not found in the original population. This technique has been particularly useful with bacteria. Because they are small, millions of bacteria can be treated with radiation or chemicals at the same time, which increases the chances of producing a useful mutant. This technique has allowed scientists to develop hundreds of useful bacterial strains. For instance, we have known for decades that certain strains of oil-digesting bacteria are effective for cleaning up oil spills. Today scientists are working to produce bacteria that can clean up radioactive substances and metal pollution in the environment.

### Polyploid Plants
Drugs that prevent the separation of chromosomes during meiosis are very useful in plant breeding. These drugs can produce cells that have many times the normal number of chromosomes. Plants grown from these cells are called polyploid because they have many sets of chromosomes. Polyploidy is usually fatal in animals. But, for reasons that are not clear, plants are much better at tolerating extra sets of chromosomes. Polyploidy can quickly produce new species of plants that are larger and stronger than their diploid relatives. A number of important crop plants, including bananas and many varieties of citrus fruits, have been produced in this way. Figure 15–4 lists several examples of polyploid plants.

#### Figure 15–4 Ploidy Numbers
Because polyploid plants are often larger than other plants, many farmers deliberately grow polyploid varieties of crops like those listed above. Interpret Tables Which plant has undergone the most dramatic changes in chromosome number?
Copying DNA

How do scientists copy the DNA of living organisms?

Until recently plant and animal breeders could only work with variations that already exist in nature. Even when breeders tried to add variation by introducing mutations, the changes they produced were unpredictable. Today genetic engineers can transfer certain genes at will from one organism to another, designing new living things to meet specific needs.

Recall from Chapter 14 that it is relatively easy to extract DNA from cells and tissues. The extracted DNA can be cut into fragments of manageable size using restriction enzymes. These restriction fragments can then be separated according to size using gel electrophoresis or another similar technique. That's the easy part. The tough part comes next: How do you find a specific gene?

The problem is huge. If we were to cut DNA from a bacterium like E. coli into restriction fragments averaging 1000 base pairs in length, we would have 4000 restriction fragments. In the human genome, we would have 3 million restriction fragments. How do we find the DNA of a single gene among millions of fragments? In some respects, it's the classic problem of finding a needle in a haystack—we have an enormous pile of hay and just one needle.

Actually, there is a way to find a needle in a haystack. We can toss the hay in front of a powerful magnet until something sticks. The hay won't stick, but a needle made of iron or steel will. Believe it or not, similar techniques can help scientists identify specific genes.

Key Questions

- How do scientists copy the DNA of living organisms?
- How is recombinant DNA used?
- How can genes from one organism be inserted into another organism?

Vocabulary

- polymerase chain reaction
- recombinant DNA
- plasmid
- genetic marker
- transgenic
- clone

Taking Notes

Preview Visuals Before you read, preview Figure 15–7 and write down any questions you may have about the figure. As you read, find answers to your questions.
Finding Genes In 1987, Douglas Prasher, a biologist at Woods Hole Oceanographic Institute in Massachusetts, wanted to find a specific gene in a jellyfish. The gene he hoped to identify is the one that codes for a molecule called green fluorescent protein, or GFP. This natural protein, found in the jellyfish shown in Figure 15–5, absorbs energy from light and makes parts of the jellyfish glow. Prasher thought that GFP from the jellyfish could be used to report when a protein was being made in a cell. If he could somehow link GFP to a specific protein, it would be a bit like attaching a light bulb to that molecule.

To find the GFP gene, Prasher studied the amino acid sequence of part of the GFP protein. By comparing this sequence to a genetic code table, he was able to predict a probable mRNA base sequence that would have coded for this sequence of amino acids. Next, Prasher used a complementary base sequence to “attract” an mRNA that matched his prediction and would bind to that sequence by base pairing. After screening a genetic “library” with thousands of different mRNA sequences from the jellyfish, he found one that bound perfectly.

After Prasher located the mRNA that produced GFP, he set out to find the actual gene. Taking a gel in which restriction fragments from the jellyfish genome had been separated, he found that one of the fragments bound tightly to the mRNA. That fragment contained the actual gene for GFP, which is now widely used to label proteins in living cells. The method he used, shown in Figure 15–6, is called Southern blotting. Today it is often quicker and less expensive for scientists to search for genes in computer databases where the complete genomes of many organisms are available.
**Polymerase Chain Reaction** Once they find a gene, biologists often need to make many copies of it. A technique known as polymerase chain reaction (PCR) allows them to do exactly that. At one end of the original piece of DNA, a biologist adds a short piece of DNA that complements a portion of the sequence. At the other end, the biologist adds another short piece of complementary DNA. These short pieces are known as primers because they prepare, or prime, a place for DNA polymerase to start working.

As Figure 15–7 suggests, the idea behind the use of PCR primers is surprisingly simple. The first step in using the polymerase chain reaction method to copy a gene is to heat a piece of DNA, which separates its two strands. Then, as the DNA cools, primers bind to the single strands. Next, DNA polymerase starts copying the region between the primers. These copies can serve as templates to make still more copies. In this way, just a few dozen cycles of replication can produce billions of copies of the DNA between the primers.

Where did Kary Mullis, the American scientist who invented PCR, find a DNA polymerase enzyme that could stand repeated cycles of heating and cooling? Mullis found it in bacteria from the hot springs of Yellowstone National Park in the northwestern United States—a powerful example of the importance of biodiversity to biotechnology!

**In Your Notebook** List the steps in the PCR method.

**Changing DNA**

How is recombinant DNA used?

Just as they were beginning to learn how to read and analyze DNA sequences, scientists began wondering if it might be possible to change the DNA of a living cell. As many of them realized, this feat had already been accomplished decades earlier. Do you remember Griffith's experiments on bacterial transformation? During transformation, a cell takes in DNA from outside the cell, and that added DNA becomes a component of the cell's own genome. Today biologists understand that Griffith's extract of heat-killed bacteria contained DNA fragments. When he mixed those fragments with live bacteria, a few of them took up the DNA molecules, transforming them and changing their characteristics. Griffith, of course, could only do this with DNA extracted from other bacteria.

**FIGURE 15–7 The PCR Method** Polymerase chain reaction is used to make multiple copies of a gene. This method is particularly useful when only tiny amounts of DNA are available. Calculate How many copies of the DNA fragment will there be after six PCR cycles?
Combining DNA Fragments

With today’s technologies, scientists can produce custom-built DNA molecules in the lab and then insert those molecules—along with the genes they carry—into living cells. The first step in this sort of genetic engineering is to build a DNA sequence with the gene or genes you’d like to insert into a cell. Machines known as DNA synthesizers can produce short pieces of DNA, up to several hundred bases in length. These synthetic sequences can then be joined to natural sequences using DNA ligase or other enzymes that splice DNA together. These same enzymes make it possible to take a gene from one organism and attach it to the DNA of another organism, as shown in Figure 15–8. The resulting molecules are called recombinant DNA. This technology relies on the fact that any pair of complementary sequences tends to bond, even if each sequence comes from a different organism.

Recombinant-DNA technology—joining together DNA from two or more sources—makes it possible to change the genetic composition of living organisms. By manipulating DNA in this way, scientists can investigate the structure and functions of genes.

Plasmids and Genetic Markers

Scientists working with recombinant DNA soon discovered that many of the DNA molecules they tried to insert into host cells simply vanished because the cells often did not copy, or replicate, the added DNA. Today scientists join recombinant DNA to another piece of DNA containing a replication “start” signal. This way, whenever the cell copies its own DNA, it copies the recombinant DNA too.

In addition to their own large chromosomes, some bacteria contain small circular DNA molecules known as plasmids. Plasmids, like those shown in Figure 15–9, are widely used in recombinant DNA studies. Joining DNA to a plasmid, and then using the recombinant plasmid to transform bacteria, results in the replication of the newly added DNA along with the rest of the cell’s genome. Plasmids are also found in yeasts, which are single-celled eukaryotes that can be transformed with recombinant DNA as well. Biologists working with yeasts can construct artificial chromosomes containing centromeres, telomeres, and replication start sites. These artificial chromosomes greatly simplify the process of introducing recombinant DNA into the yeast genome.
Figure 15–10 shows how bacteria can be transformed using recombinant plasmids. First, the DNA being used for transformation is joined to a plasmid. The plasmid DNA contains a signal for replication, helping to ensure that if the DNA does get inside a bacterial cell, it will be replicated. In addition, the plasmid also has a genetic marker, such as a gene for antibiotic resistance. A genetic marker is a gene that makes it possible to distinguish bacteria that carry the plasmid from those that don’t. Using genetic markers, researchers can mix recombinant plasmids with a culture of bacteria, add enough DNA to transform just one cell in a million, and still locate that one cell. After transformation, the culture is treated with an antibiotic. Only those rare cells that have been transformed survive, because only they carry the resistance gene.

In Your Notebook Write a summary of the process of plasmid DNA transformation.

Inserting Genetic Markers

1. Write a random DNA sequence on a long strip of paper to represent an organism’s genome.
2. Have your partner write a short DNA sequence on a short strip of paper to represent a marker gene.
3. Using the chart your teacher gives you, work with your partner to figure out how to insert the marker gene into the genome.

Analyze and Conclude

1. Apply Concepts Which restriction enzyme did you use? Why?
2. Use Models What kind of molecule did you and your partner develop?
Transgenic Organisms

How can genes from one organism be inserted into another organism?

The universal nature of the genetic code makes it possible to construct organisms that are transgenic, containing genes from other species. Transgenic organisms can be produced by the insertion of recombinant DNA into the genome of a host organism. Like bacterial plasmids, the DNA molecules used for transformation of plant and animal cells contain genetic markers that help scientists identify which cells have been transformed.

Transgenic technology was perfected using mice in the 1980s. Genetic engineers can now produce transgenic plants, animals, and microorganisms. By examining the traits of a genetically modified organism, it is possible to learn about the function of the transferred gene. This ability has contributed greatly to our understanding of gene regulation and expression.

Transgenic Plants Many plant cells can be transformed using Agrobacterium. In nature this bacterium inserts a small DNA plasmid that produces tumors in a plant's cells. Scientists can deactivate the plasmid’s tumor-producing gene and replace it with a piece of recombinant DNA. The recombinant plasmid can then be used to infect and transform plant cells, as shown in Figure 15–11.

There are other ways to produce transgenic plants as well. When their cell walls are removed, plant cells in culture will sometimes take up DNA on their own. DNA can also be injected directly into some cells. If transformation is successful, the recombinant DNA is integrated into one of the plant cell's chromosomes.

Transgenic Animals Scientists can transform animal cells using some of the same techniques used for plant cells. The egg cells of many animals are large enough that DNA can be injected directly into the nucleus. Once the DNA is in the nucleus, enzymes that are normally responsible for DNA repair and recombination may help insert the foreign DNA into the chromosomes of the injected cell.

Recently it has become possible to eliminate particular genes by carefully engineering the DNA molecules that are used for transformation. The DNA molecules can be constructed with two ends that will sometimes recombine with specific sequences in the host chromosome. Once they do, the host gene normally found between those two sequences may be lost or specifically replaced with a new gene. This kind of gene replacement has made it possible to pinpoint the specific functions of genes in many organisms, including mice.
Cloning. **A clone** is a member of a population of genetically identical cells produced from a single cell. The technique of cloning uses a single cell from an adult organism to grow an entirely new individual that is genetically identical to the organism from which the cell was taken.

Cloned colonies of bacteria and other microorganisms are easy to grow, but this is not always true of multicellular organisms, especially animals. Clones of animals were first produced in 1952 using amphibian tadpoles. In 1997, Scottish scientist Ian Wilmut stunned biologists by announcing that he had produced a sheep, called Dolly, by cloning.

Figure 15–12 shows the basic steps by which an animal can be cloned. First, the nucleus of an unfertilized egg cell is removed. Next, the egg cell is fused with a donor cell that contains a nucleus, taken from an adult. The resulting diploid egg develops into an embryo, which is then implanted in the uterine wall of a foster mother, where it develops until birth. Cloned cows, pigs, mice, and even cats have since been produced using similar techniques.

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**4. Design an experiment to find a way to treat disorders caused by a single gene. State your hypothesis and list the steps you would follow.**

*Hint: Think about the uses of recombinant DNA.*
Applications of Genetic Engineering

Key Questions
- How can genetic engineering benefit agriculture and industry?
- How can recombinant-DNA technology improve human health?
- How is DNA used to identify individuals?

Vocabulary
- gene therapy
- DNA microarray
- DNA fingerprinting
- forensics

Taking Notes
Outline
Make an outline of this lesson by using the green and blue headings. As you read, take notes on the different applications of genetic engineering.

Agriculture and Industry

How can genetic engineering benefit agriculture and industry?

Everything we eat and much of what we wear come from living organisms. Not surprisingly, then, researchers have used genetic engineering to try to improve the products we get from plants and animals. Ideally, genetic modification could lead to better, less expensive, and more nutritious food as well as less-harmful manufacturing processes.

GM Crops
Since their introduction in 1996, genetically modified (GM) plants, like the soybeans in Figure 15–13, have become an important component of our food supply. In 2007, GM crops made up 92 percent of soybeans, 86 percent of cotton, and 80 percent of corn grown in the United States. One type of modification, which has already proved particularly useful to agriculture, uses bacterial genes that produce a protein known as Bt toxin. While this toxin is harmless to humans and most other animals, enzymes in the digestive systems of insects convert Bt to a form that kills the insects. Plants with the Bt gene, then, do not have to be sprayed with pesticides. In addition, they produce higher yields of crops.

Resistance to insects is just one useful characteristic being engineered into crops. Others include resistance to herbicides, which are chemicals that destroy weeds, and resistance to viral infections. Some transgenic plants may soon produce foods that are resistant to rot and spoilage. And engineers are currently developing GM plants that may produce plastics for the manufacturing industry.

THINK ABOUT IT
Have you eaten any genetically modified food lately? Don’t worry if you’re not sure how to answer that question. In the United States and many other countries, this kind of food doesn’t have to be labeled in grocery stores or markets. But if you’ve eaten corn, potatoes, or soy products in any of your meals this week, chances are close to 100 percent that you’ve eaten foods modified in some way by genetic engineering.

FIGURE 15–13 GM Soybeans
Genetically modified soybeans are a popular crop in the United States.
GM Animals  Transgenic animals are also becoming more important to our food supply. For example, about 30 percent of the milk in U.S. markets comes from cows that have been injected with hormones made by recombinant-DNA techniques to increase milk production. Pigs can be genetically modified to produce more lean meat or high levels of healthy omega-3 acids. Using growth-hormone genes, scientists have developed transgenic salmon that grow much more quickly than wild salmon. This effort makes it practical to grow these nutritious fish in captive aquaculture facilities that do not threaten wild populations.

When scientists in Canada combined spider genes into the cells of lactating goats, the goats began to manufacture silk along with their milk. By extracting polymer strands from the milk and weaving them into thread, we can create a light, tough, and flexible material that could be used in such applications as military uniforms, medical sutures, and tennis racket strings. Scientists are now using human genes to develop antibacterial goat milk.

Researchers hope that cloning will enable them to make copies of transgenic animals, which would increase the food supply and could even help save endangered species. In 2008, the U.S. government approved the sale of meat and milk from cloned animals. Many farmers and ranchers hope that cloning technology will allow them to duplicate the best qualities of prize animals without the time and complications of traditional breeding.

In Your Notebook  Describe the ways in which GM organisms can benefit agriculture and industry.

Genetically Modified Crops in the United States

U.S. farmers have adopted GM crops widely since their introduction in 1996. Soybeans, cotton, and corn have been modified to tolerate herbicides and resist insect damage. The graph at the right summarizes the extent to which these crops were adopted between 1996 and 2007. The modified traits shown here include herbicide tolerance (HT) and insect resistance (Bt).

1. **Analyze Data** Which two crops were most widely and rapidly adopted?
2. **Draw Conclusions** Why do you think the levels of adoption fell at certain points over the period?
3. **Predict** What do you think will happen to HT soybeans and HT corn over the next few years? Why? Use the graph to support your prediction.
4. **Infer** Why do you think an increasing number of farmers have chosen to grow crops with herbicide tolerance?

**Genetically Modified Crops in the U.S.**

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Source: U.S. Department of Agriculture Economic Research Service Data Sets

**Apply Concepts** What action do scientists hope the lysozyme gene will take in genetically modified goats?
Health and Medicine

**How can recombinant-DNA technology improve human health?**

Biotechnology, in its broadest sense, has always been part of medicine. Early physicians extracted substances from plants and animals to cure their patients. Twentieth-century medicine saw the use of vaccination to save countless lives.

Today, recombinant-DNA technology is the source of some of the most important and exciting advances in the prevention and treatment of disease.

**Preventing Disease** One interesting development in transgenic technology is golden rice, shown in Figure 15–15. This rice contains increased amounts of provitamin A, also known as beta-carotene—a nutrient that is essential for human health. Provitamin A deficiencies produce serious medical problems, including infant blindness. There is hope that provitamin A-rich golden rice will help prevent these problems. Other scientists are developing transgenic plants and animals that produce human antibodies to fight disease.

In the future, transgenic animals may provide us with an ample supply of our own proteins. Several laboratories have engineered transgenic sheep and pigs that produce human proteins in their milk, making it easy to collect and refine the proteins. Many of these proteins can be used in disease prevention.

**Medical Research** Transgenic animals are often used as test subjects in medical research. In particular they can simulate human diseases in which defective genes play a role. Scientists use models based on these simulations to follow the onset and progression of diseases and to construct tests of new drugs that may be useful for treatment. This approach has been used to develop models for disorders like Alzheimer’s disease and arthritis.

**Treating Disease** When recombinant-DNA techniques were developed for bacteria, biologists realized almost immediately that the technology held the promise to do something that had never been done before—to make important proteins that could prolong and even save human lives. For example, human growth hormone, which is used to treat patients suffering from pituitary dwarfism, was once scarce. Human growth hormone is now widely available because it is mass-produced by recombinant bacteria. Other products now made in genetically engineered bacteria include insulin to treat diabetes, blood-clotting factors for hemophiliacs, and potential cancer-fighting molecules such as interleukin-2 and interferon.
If an individual is suffering from a missing or defective gene, can we replace that gene with a healthy one and fix the problem? The experimental field of gene therapy is attempting to answer that question. Gene therapy is the process of changing a gene to treat a medical disease or disorder. In gene therapy, an absent or faulty gene is replaced by a normal, working gene. This process allows the body to make the protein or enzyme it needs, which eliminates the cause of the disorder.

The idea of using gene therapy to cure disease arose from the major advances in molecular biology made in the past 20 years, including the Human Genome Project. Figure 15–16 shows one of the ways in which researchers have attempted to carry out gene therapy. To deliver the correct, or therapeutic, gene to the affected, or target, cells, researchers first engineer a virus that cannot reproduce or cause harmful effects. They place DNA containing the therapeutic gene into the modified virus, and then they infect the patient’s cells with it. In theory the virus will insert the healthy gene into the target cell and correct the defect. The challenge, however, is to deliver a gene that works correctly over the long term. For all the promise it holds, in most cases gene therapy remains a high-risk experimental procedure. For gene therapy to become an accepted treatment, we need more reliable ways to insert working genes and to ensure that the DNA used in the therapy does no harm.

Genetic Testing If two prospective parents suspect they are carrying the alleles for a genetic disorder such as cystic fibrosis (CF), how could they find out for sure? Because the CF allele has slightly different DNA sequences from its normal counterpart, genetic tests using labeled DNA probes can distinguish it. Like many genetic tests, the CF test uses specific DNA sequences that detect the complementary base sequences found in the disease-causing alleles. Other genetic tests search for changes in cutting sites of restriction enzymes. Some use PCR to detect differences between the lengths of normal and abnormal alleles. Genetic tests are now available for diagnosing hundreds of disorders.

![Diagram](image-url)
Preparing the cDNA Probe
1. mRNA samples are isolated from two different types of cells or tissues, such as cancer cells and normal cells.

2. Enzymes are used to prepare complementary DNA molecules (cDNA) from both groups of mRNA. Contrasting fluorescent labels are attached to both groups of cDNA (red to one, green to the other).

3. DNA fragments corresponding to different genes are bound to the wells in a microarray plate.

4. Single strands of DNA are attached to wells in the plate.

Combining the Probe and Microarray Samples
5. Labeled cDNA molecules bind to complementary sequences on the plate.

Examining Active Genes
Even though all of the cells in the human body contain identical genetic material, the same genes are not active in every cell. By studying which genes are active and which are inactive in different cells, scientists can understand how the cells function normally and what happens when genes don’t work as they should. Today, scientists use DNA microarray technology to study hundreds or even thousands of genes at once to understand their activity levels. A DNA microarray is a glass slide or silicon chip to which spots of single-stranded DNA have been tightly attached. Typically each spot contains a different DNA fragment. Different colored tags are used to label the source of DNA.

Suppose, for example, that you want to compare the genes abnormally expressed in cancer cells with genes in normal cells from the same tissue. After isolating mRNA from both types of cells, you would use an enzyme to copy the mRNA base sequence into single-stranded DNA labeled with fluorescent colors—red for the cancer cell and green for the normal cell. Next you would mix both samples of labeled DNA together and let them compete for binding to the complementary DNA sequences already in the microarray. If the cancer cell produces more of a particular form of mRNA, then more red-labeled molecules will bind at the spot for that gene, turning it red. Where the normal cell produces more mRNA for another gene, that spot will be green. Where there is no difference between the two cell types, the spot will be yellow because it contains both colors.

Figure 15–18 shows how a DNA microarray is constructed and used.
Chromosomes contain many regions with repeated DNA sequences that do not code for proteins. These vary from person to person. Here, one sample has 12 repeats between genes A and B, while the second sample has 9 repeats between the same genes.

Restriction enzymes are used to cut the DNA into fragments containing genes and repeats. Note that the repeat fragments from these two samples are of different lengths.

The restriction fragments are separated according to size using gel electrophoresis. The DNA fragments containing repeats are then labeled using radioactive probes. This labeling produces a series of bands—the DNA fingerprint.

Personal Identification

How is DNA used to identify individuals?

The complexity of the human genome ensures that no individual is exactly like any other genetically—except for identical twins, who share the same genome. Molecular biology has used this fact to develop a powerful tool called DNA fingerprinting for use in identifying individuals. DNA fingerprinting analyzes sections of DNA that may have little or no function but that vary widely from one individual to another. This method is shown in Figure 15–19. First, restriction enzymes cut a small sample of human DNA. Next, gel electrophoresis separates the restriction fragments by size. Then, a DNA probe detects the fragments that have highly variable regions, revealing a series of variously sized DNA bands. If enough combinations of enzymes and probes are used, the resulting pattern of bands can be distinguished statistically from that of any other individual in the world. DNA samples can be obtained from blood, sperm, or tissue—even from a hair strand if it has tissue at the root.

Forensic Science DNA fingerprinting has been used in the United States since the late 1980s. Its precision and reliability have revolutionized forensics—the scientific study of crime scene evidence. DNA fingerprinting has helped solve crimes, convict criminals, and even overturn wrongful convictions. To date, DNA evidence has saved more than 110 wrongfully convicted prisoners from death sentences.

DNA forensics is used in wildlife conservation as well. African elephants are a highly vulnerable species. Poachers, who slaughter the animals mainly for their precious tusks, have reduced their population dramatically. To stop the ivory trade, African officials now use DNA fingerprinting to identify the herds from which black-market ivory has been taken.

In Your Notebook Describe the process of DNA fingerprinting.
Establishing Relationships. In cases of disputed paternity, how does our justice system determine the rightful father of a child? DNA fingerprinting makes it easy to find alleles carried by the child that do not match those of the mother. Any such alleles must come from the child’s biological father, and they will show up in his DNA fingerprint. The probability that those alleles will show up in a randomly picked male is less than 1 in 100,000. This means the likelihood that a given male is the child’s father must be higher than 99.99 percent to confirm his paternity.

When genes are passed from parent to child, genetic recombination scrambles the molecular markers used for DNA fingerprinting, so ancestry can be difficult to trace. There are two ways to solve this problem. The Y chromosome never undergoes crossing over, and only males carry it. Therefore, Y chromosomes pass directly from father to son with few changes. The same is true of the small DNA molecules found in mitochondria. These are passed, with very few changes, from mother to child in the cytoplasm of the egg cell.

Because mitochondrial DNA (mtDNA) is passed directly from mother to child, your mtDNA is the same as your mother’s mtDNA, which is the same as her mother’s mtDNA. This means that if two people have an exact match in their mtDNA, then there is a very good chance that they share a common maternal ancestor. Y-chromosome analysis has been used in the same way and has helped researchers settle longstanding historical questions. One such question—did President Thomas Jefferson father the child of a slave?—may have been answered in 1998. DNA testing showed that descendants of the son of Sally Hemings, a slave on Jefferson’s Virginia estate, carried his Y chromosome. This result suggests Jefferson was the child’s father, although the Thomas Jefferson Foundation continues to challenge that conclusion.

Review Key Concepts

1. **a. Review** Give two practical applications for transgenic plants and two for transgenic animals.
   **b. Infer** What might happen if genetically modified fish were introduced into an aquaculture facility?

2. **a. Review** Name three uses for recombinant-DNA technology.
   **b. Apply Concepts** Medicines in the body interact with the body’s proteins. How might normal variations in your genes affect your response to different medicines?

3. **a. Review** List the steps in DNA fingerprinting.
   **b. Infer** Why is DNA fingerprinting more accurate if the samples are cut with more than one restriction enzyme?

Practice Problem

4. Using restriction enzymes and gel electrophoresis, write the steps of a protocol in which you test for the allele of a gene that causes a genetic disorder.
Artificial Life?

In 2008, scientists at the J. Craig Venter Institute in Rockville, Maryland, produced a synthetic genome with more than half a million DNA base pairs. It may not be long before artificial cells containing similar genomes can be grown in the laboratory. How? First a complete DNA molecule, containing the minimum set of the genetic information needed to keep a cell alive, is produced in the laboratory. Then, that molecule is inserted into a living cell to replace the cell's DNA. The result is a cell whose genome is entirely synthetic. Scientists hope this technique can help them design cells for specific purposes, like capturing solar energy or manufacturing biofuels.

**WRITING**

What are the ethical issues in producing synthetic organisms? If you were a scientist working on the latest breakthroughs, how would you address those issues? Describe your ideas in an essay.

Daniel G. Gibson, a scientist at the J. Craig Venter Institute, and his team produced a completely synthetic genome of a bacterium, *Mycoplasma genitalium*.

This series of photomicrographs of the synthetic genome was taken over approximately 0.6 second. The genome contains nearly 583,000 base pairs of DNA.
15.4 Ethics and Impacts of Biotechnology

Key Questions
- What privacy issues does biotechnology raise?
- Are GM foods safe?
- Should genetic modifications to humans and other organisms be closely regulated?

Taking Notes
Two-Column Chart As you read, write down the opposing viewpoints on each ethical issue.

THINK ABOUT IT
- Years ago a science fiction movie titled *Gattaca* speculated about a future world in which genetics determines people’s ability to get ahead in life. In the movie, schooling, job prospects, and legal rights are rigidly determined by an analysis of the individual’s DNA on the day he or she is born. Are we moving closer to this kind of society?

Profits and Privacy
- What privacy issues does biotechnology raise?

Private biotechnology and pharmaceutical companies do much of the research involving GM plants and animals. Their goal is largely to develop profitable new crops, drugs, tests, or other products. Like most inventors, they protect their discoveries and innovations with patents. A patent is a legal tool that gives an individual or company the exclusive right to profit from its innovations for a number of years.

Patenting Life
When you think about patents, you probably think about an inventor protecting a new machine or device. But molecules and DNA sequences can be patented, too. In fact, roughly one fifth of the known genes in the human genome are now patented commercially. Even laboratory techniques like PCR have been patented. When a scientist wants to run a PCR test, he or she must pay a fee for the license to use this process.

The ability to patent is meant to spur discovery and advancements in medicine and industry. After all, patent holders stand a good chance of reaping large financial rewards. Sometimes, though, patent holders demand high fees that block other scientists from exploring certain lines of research. That was the case in developing provitamin A–enriched golden rice, a GM plant described in Lesson 15.3. Even after the rice was developed, patent disputes kept it out of the hands of farmers for years.

Now consider the information held in your own genome. 
- Do you have exclusive rights to your DNA? Should you, like patent holders, be able to keep your genetic information confidential? When it comes to your own DNA, how much privacy are you entitled to?
**Genetic Ownership**  One of the most hallowed sites in the United States is the one shown in Figure 15–21. It is the Tomb of the Unknowns in Arlington National Cemetery, near Washington, D.C. Buried here are the remains of unidentified American soldiers who fought our nation’s wars. The tomb also serves as a focal point for the honor and remembrance of those service members lost in combat whose bodies have never been recovered.

Biotechnology offers hope that there will never be another unknown soldier. The U.S. military now requires all personnel to give a DNA sample when they begin their service. Those DNA samples are kept on file and used, if needed, to identify the remains of individuals who perish in the line of duty. In many ways, this practice is a comfort to military families, who can be assured that the remains of a loved one can be properly identified for burial.

But what if the government wants to use an individual’s DNA sample for another purpose, in a criminal investigation or a paternity suit? What if health-insurance providers manage their healthcare policies based on a genetic predisposition to disease? For example, suppose that, years after giving a DNA sample, an individual is barred from employment or rejected for health insurance because of a genetic defect detected in the sample. Would this be a fair and reasonable use of genetic information?

After considering this issue for years, United States Congress passed the Genetic Information Nondiscrimination Act, which became law in 2008. This act protects Americans against discrimination based on their genetic information. Physicians and ethicists hope this will lead to more effective use of personal genetic information, without fear of prejudice in obtaining health insurance or employment.

**Safety of Transgenics**

**Are GM foods safe?**

Much controversy exists concerning foods that have had their DNA altered through genetic engineering. The majority of GM crops today are grown in the United States, although farmers around the world have begun to follow suit. Are the foods from GM crops the same as those prepared from traditionally bred crops?

**Pros of GM Foods.** The companies producing seeds for GM crops would say that GM plants are actually better and safer than other crops. Farmers choose them because they produce higher yields, reducing the amount of land and energy that must be devoted to agriculture and lowering the cost of food for everyone.

Insect-resistant GM plants need little, if any, insecticide to grow successfully, reducing the chance that chemical residues will enter the food supply and lessening damage to the environment. In addition, GM foods have been widely available for more than a decade. Careful studies of such foods have provided no scientific support for concerns about their safety, and it does seem that foods made from GM plants are safe to eat.
Cons of GM Foods. Critics acknowledge some benefits of genetically modified foods, but they also point out that no long-term studies have been made of the hazards these foods might present.

Even if GM food itself presents no hazards, there are many serious concerns about the unintended consequences that a shift to GM farming and ranching may have on agriculture.

Some worry that the insect resistance engineered into GM plants may threaten beneficial insects, killing them as well as crop pests. Others express concerns that use of plants resistant to chemical herbicides may lead to overuse of these weed-killing compounds.

Another concern is that the patents held on GM seeds by the companies that produce them may prove costly enough to force small farmers out of business, especially in the developing world.

It is not clear whether any of these concerns should block the wider use of these new biotechnologies, but it is certain that they will continue to prove controversial in the years ahead.

In the United States, current federal regulations treat GM foods and non-GM foods equally. As a result, GM foods are not required to undergo special safety testing before entering the market. No additional labeling is required to identify a product as genetically modified unless its ingredients are significantly different from its conventional counterpart. The possibility that meat from GM animals may soon enter the food supply has heightened concerns about labeling. As a result, some states have begun to consider legislation to require the labeling of GM foods, thereby providing consumers with an informed choice.

Ethics of the New Biology

Should genetic modifications to humans and other organisms be closely regulated?

“Know yourself.” The ancient Greeks carved this good advice in stone, and it has been guiding human behavior ever since. Biotechnology has given us the ability to know ourselves more and more. With this knowledge, however, comes responsibility.

You’ve seen how easy it is to move genes from one organism to another. For example, the GFP gene can be extracted from a jellyfish and spliced onto genes coding for important cellular proteins. This ability has led to significant new discoveries about how cells function.

The same GFP technology was used to create the fluorescent zebra fish shown in Figure 15–22. These fish—along with fluorescent mice, tadpoles, rabbits, and even cats—have all contributed to our understanding of cells and proteins. But the ability to alter life forms for any purpose, scientific or nonscientific, raises important questions.

Just because we have the technology to modify an organism’s characteristics, are we justified in doing so?
Review Key Concepts

1. a. **Review** What is a patent?
b. **Apply Concepts** How could biotechnology affect your privacy?

2. a. **Review** What are genetically modified foods?
b. **Form an Opinion** Should a vegetarian be concerned about eating a GM plant that contains DNA from a pig gene? Support your answer with details from the text.

3. a. **Review** What are the main concerns about genetic engineering discussed in this lesson or elsewhere in the chapter?
b. **Pose Questions** Write three specific questions about the ethical, social, or legal implications of genetic engineering that do not appear in this lesson. For example, how does personal genetic information affect self-identity?

4. **Biologists may one day be able to use genetic engineering to alter a child’s inherited traits. Under what circumstances, if any, should this ability be used? Write a persuasive paragraph expressing your opinion.

It would indeed be marvelous if biotechnology enabled us to cure hemophilia, cystic fibrosis, or other genetic diseases. But if human cells can be manipulated to cure disease, should biologists try to engineer taller people or change their eye color, hair texture, sex, blood group, or appearance? What will happen to the human species when we gain the opportunity to design our bodies or those of our children? What will be the consequences if biologists develop the ability to clone human beings by making identical copies of their cells? These are questions with which society must come to grips.

The goal of biology is to gain a better understanding of the nature of life. As our knowledge increases, however, so does our ability to manipulate the genetics of living things, including ourselves. In a democratic nation, all citizens—not just scientists—are responsible for ensuring that the tools science has given us are used wisely. This means that you should be prepared to help develop a thoughtful and ethical consensus of what should and should not be done with the human genome. To do anything less would be to lose control of two of our most precious gifts: our intellect and our humanity.

**FIGURE 15–22 Gaining More Understanding** These fluorescent zebra fish were originally bred to help scientists detect environmental pollutants. Today, studying fluorescent fish is helping us understand cancer and other diseases. The fish are also sold to the public at a profit.

**WRITE ABOUT SCIENCE**

**Persuasion**

4. Biologists may one day be able to use genetic engineering to alter a child’s inherited traits. Under what circumstances, if any, should this ability be used? Write a persuasive paragraph expressing your opinion.
Pre-Lab: Using DNA to Solve Crimes

Problem How can DNA samples be used to connect a suspect to a crime scene?

Materials gel block, electrophoresis chamber, buffer solution, 250-mL beaker, metric ruler, DNA samples, micropipettes, 9-volt batteries, electric cords, staining tray, DNA stain, 100-mL graduated cylinder, clock or timer

Lab Manual Chapter 15 Lab

Skills Focus Measure, Compare and Contrast, Draw Conclusions

Connect to the Scientists who worked on the Human Genome Project had to develop methods for sequencing and identifying genes. Those methods have since been used for many other applications. For example, genetically altered bacteria are used to produce large amounts of life-saving drugs. Another example is the use of DNA evidence to solve crimes. In this lab, you will prepare and compare DNA “fingerprints,” or profiles.

Background Questions

a. Review What characteristic of the human genome makes DNA a powerful tool for solving crimes?

b. Review What do the segments of DNA that are used to make DNA profiles have in common?

c. Apply Concepts When forensic scientists want to determine whether two DNA samples come from the same person, they analyze more than one section of DNA. Why would the results be less reliable if the scientists compared only one section of DNA?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. Control Variables Why must you use a new pipette to load each DNA sample?

2. Relate Cause and Effect Why will the DNA samples separate into bands as they move through the gel?

3. Infer Why is purple tracking dye added to the DNA samples?
Genetic engineering allows scientists to manipulate the genomes of living things. Scientists can use bacteria to insert the DNA of one organism into another organism. Recombinant DNA has applications for agriculture, industry, medicine, and forensics. At the same time, there are ethical, legal, safety, and social issues surrounding the use of genetic engineering.

**15.1 Selective Breeding**

Humans use selective breeding, which takes advantage of naturally occurring genetic variation, to pass wanted traits on to the next generation of organisms.

Breeders can increase the genetic variation in a population by introducing mutations, which are the ultimate source of biological diversity.

**15.2 Recombinant DNA**

The first step in using the polymerase chain reaction method to copy a gene is to heat a piece of DNA, which separates its two strands. Then, as the DNA cools, primers bind to the single strands. Next, DNA polymerase starts copying the region between the primers. These copies can serve as templates to make still more copies.

Recombinant-DNA technology—joining together DNA from two or more sources—makes it possible to change the genetic composition of living organisms.

Transgenic organisms can be produced by the insertion of recombinant DNA into the genome of a host organism.

**15.3 Applications of Genetic Engineering**

Ideally, genetic modification could lead to better, less expensive, and more nutritious food as well as less-harmful manufacturing processes.

Recombinant-DNA technology is advancing the prevention and treatment of disease.

DNA fingerprinting analyzes sections of DNA that vary widely from one individual to another.

**15.4 Ethics and Impacts of Biotechnology**

Should you, like patent holders, be able to keep your genetic information confidential?

Careful studies of GM foods have provided no scientific support for concerns about their safety.

There are many concerns about unintended consequences that a shift to GM farming and ranching may have on agriculture.

Just because we have the technology to modify an organism’s characteristics, are we justified in doing so?

**Think Visually**

Complete the following concept map.

1. Breeding
2. New Organisms
3. Inbreeding

---

**Crossword**

- gene therapy (431)
- DNA fingerprinting (433)
- DNA microarray (432)
- forensics (433)
- selective breeding (418)
- inbreeding (419)
- hybridization (419)
- biotechnology (419)
- polymerase chain reaction (423)
- recombinant DNA (424)
- plasmid (424)
- genetic marker (425)
- transgenic (426)
- clone (427)
15.1 Selective Breeding

Understand Key Concepts

1. Crossing dissimilar individuals to bring together their best characteristics is called
   a. domestication.  c. hybridization.
   b. inbreeding.  d. polyploidy.

2. Crossing individuals with similar characteristics so that those characteristics will appear in their offspring is called
   a. inbreeding.  c. recombination.
   b. hybridization.  d. polyploidy.

3. Taking advantage of naturally occurring variations in organisms to pass wanted traits on to future generations is called
   a. selective breeding.  c. hybridization.
   b. inbreeding.  d. mutation.

4. How do breeders produce genetic variations that are not found in nature?

5. What is polyploidy? When is this condition useful?

Think Critically

6. Propose a Solution Suppose a plant breeder has a thornless rose bush with scentless pink flowers, a thorny rose bush with sweet-smelling yellow flowers, and a thorny rose bush with scentless purple flowers. How might this breeder develop a pure variety of thornless, sweet-smelling purple roses?

7. Compare and Contrast Hybridization and inbreeding are important methods used in selective breeding. How are the methods similar? How are they different?

15.2 Recombinant DNA

Understand Key Concepts

8. Organisms that contain genes from other organisms are called
   a. transgenic.  c. donors.
   b. mutagenic.  d. clones.

9. What process is shown below?
   a. cloning
   b. transformation
   c. hybridization
   d. polymerase chain reaction

10. When cell transformation is successful, the recombinant DNA
    a. undergoes mutation.
    b. is treated with antibiotics.
    c. becomes part of the transformed cell’s genome.
    d. becomes a nucleus.

11. Bacteria often contain small circular molecules of DNA known as
    a. clones.  c. plasmids.
    b. chromosomes.  d. hybrids.

12. A member of a population of genetically identical cells produced from a single cell is a
    a. clone.  c. mutant.
    b. plasmid.  d. sequence.

13. Describe what happens during a polymerase chain reaction.

14. Explain what genetic markers are and describe how scientists use them.

15. How does a transgenic plant differ from a hybrid plant?
Think Critically
16. **Apply Concepts** Describe one or more advantages of producing insulin and other proteins through genetic engineering.

17. **Apply Concepts** Bacteria and human beings are very different organisms. Why is it sometimes possible to combine their DNA and use a bacterium to make a human protein?

15.3 Applications of Genetic Engineering

Understand Key Concepts
18. Which of the following characteristics is often genetically engineered into crop plants?
   - a. improved flavor
   - b. resistance to herbicides
   - c. shorter ripening times
   - d. thicker stems

19. A substance that has been genetically engineered into transgenic rice has the potential to treat
   - a. cancer.
   - b. high blood pressure.
   - c. vitamin A deficiency.
   - d. malaria.

20. Physicians can screen for a genetic disorder using
   - a. a DNA microarray.
   - b. PCR.
   - c. restriction enzyme analysis.
   - d. DNA sequencing.

21. Describe how a DNA microarray might be used to distinguish normal cells from cancer cells.

22. Describe two important uses for DNA fingerprinting.

Think Critically
23. **Infer** If a human patient’s bone marrow was removed, altered genetically, and reimplanted, would the change be passed on to the patient’s children? Explain your answer.

A CASE OF MISTaken IDENTITY

The first suspect was lucky: Twenty years earlier, it would have been an open-and-shut case. But by 1998, DNA fingerprinting was widely available. After the police took the suspect into custody, forensic scientists tested the DNA in the bloodstains on his shirt. Within a few hours, they knew they had the wrong suspect. Before long, the police caught the real attacker, who was subsequently tried and convicted of the crime.

1. **Infer** How did the investigators determine that the person they took into custody was not guilty of this crime?

2. **Apply Concepts** Did the DNA evidence from the bloodstains come from the red blood cells, the white blood cells, or both? Explain your answer.

3. **Predict** What if the initial suspect was related to the victim? Would that have changed the result? Why or why not?

4. **Connect to the Big Idea** What might have happened if this crime were committed before DNA fingerprinting was discovered? Describe the series of events that might have taken place after police took in the first suspect.
30. **Apply Concepts** Copy the following DNA sequence and write its complementary strand.

\[ \text{ATGAGATCTACGGAATTCTCAAGCTTGAATCG} \]

Where will each restriction enzyme in the table cut the DNA strand?

**DNA Restriction Enzymes**

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Recognition Sequence</th>
</tr>
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<tr>
<td>BglII</td>
<td>AGATCT</td>
</tr>
<tr>
<td>EcoRI</td>
<td>GAATTC</td>
</tr>
<tr>
<td>HindIII</td>
<td>AAGCTT</td>
</tr>
</tbody>
</table>

31. **Explanation** Your local newspaper has published an editorial against using genetic modification. It asserts that GM is still too new, and traditional selective breeding can accomplish the same things as GM. Write a letter to the editor supporting or opposing this position.

32. **Assess the Big Idea** Briefly describe the major steps involved in inserting a human gene into a bacterium.
Multiple Choice

1. Polyploidy may instantly produce new types of organisms that are larger and stronger than their diploid relatives in
   A. animals.  
   B. plants.  
   C. bacteria.  
   D. fungi.

2. Which of the following characteristics does NOT apply to a plasmid?
   A. made of DNA
   B. found in bacterial cells
   C. has circular loops
   D. found in animal cells

3. To separate DNA fragments from one another, scientists use
   A. polymerase chain reaction.
   B. DNA microarrays.
   C. gel electrophoresis.
   D. restriction enzymes.

4. Restriction enzymes cut DNA molecules
   A. into individual nucleotides.
   B. at random locations.
   C. at short sequences specific to each type of enzyme.
   D. into equal-sized pieces.

5. The expression of thousands of genes at one time can be followed using
   A. polymerase chain reaction.
   B. plasmid transformation.
   C. restriction enzymes.
   D. DNA microarrays.

6. Genetically engineered crop plants can benefit farmers by
   A. reducing the amount of land that is required to grow them.
   B. introducing chemicals into the environment.
   C. increasing an animal’s resistance to antibiotics.
   D. changing the genomes of other crop plants.

7. Genetic markers allow scientists to
   A. clone animals.
   B. separate strands of DNA.
   C. synthesize antibiotics.
   D. identify transformed cells.

Questions 8–9

The graph below shows the number of accurate copies of DNA produced by polymerase chain reaction.

8. What can you conclude about cycles 18 through 26?
   A. PCR produced accurate copies of template DNA at an exponential rate.
   B. The amount of DNA produced by PCR doubled with each cycle.
   C. The DNA copies produced by PCR were not accurate copies of the original DNA template.
   D. The rate at which PCR produced accurate copies of template DNA fell in later cycles.

9. Based on the graph, which of the following might have happened between cycles 26 and 28?
   A. PCR stopped producing accurate copies of the template.
   B. The rate of reaction increased.
   C. All of the template DNA was used up.
   D. A mutation occurred.

Open-Ended Response

10. Why are bacteria able to make human proteins when a human gene is inserted in them with a plasmid?
Unit Project

Genetics Collage

Genetics is a fascinating field of study and is becoming increasingly important to society. A local genetics laboratory in your town wants to increase public awareness of the importance of genetics. To do so, it has decided to hold a scholarship competition. The scholarship will go to the student(s) who create the best educational collage related to topics in genetics.

Your Task
Using magazine and newspaper clippings, Internet sources, and art materials to make a colorful collage. The images should relate to three central questions.
1) Why is DNA important to a cell?
2) Why is DNA important to you, as a human being?
3) Why is DNA important to society as a whole?
Be sure to
• communicate answers to the above questions in the images, words and phrases you choose.
• carefully design your collage so that it is clear and organized.

Assessment Rubric

<table>
<thead>
<tr>
<th>Score</th>
<th>Scientific Content</th>
<th>Quality of Collage</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Collage includes many important and thoughtful images related to the three central questions. Student demonstrates a deep understanding of genetics topics.</td>
<td>The collage is clear, organized, and creative.</td>
</tr>
<tr>
<td>3</td>
<td>Collage includes important images related to the three central questions. Student demonstrates an adequate understanding of genetics topics.</td>
<td>The collage is well designed and organized.</td>
</tr>
<tr>
<td>2</td>
<td>Collage is missing some important ideas and/or includes several insignificant ideas. Student demonstrates a limited level of understanding of genetics topics.</td>
<td>The collage could be better designed and organized.</td>
</tr>
<tr>
<td>1</td>
<td>Collage is missing several important ideas. Student demonstrates significant misunderstandings.</td>
<td>The collage is unclear and lacks a solid design.</td>
</tr>
</tbody>
</table>

Reflection Questions
1. Score your collage using the rubric below. What score did you give yourself?
2. What did you do well in this project?
3. What about your collage needs improvement?
4. What could a person who didn’t know much about DNA learn from your collage?
Dear Colleague,

In 1992, a doctor at Tufts Medical School published a book entitled The Antibiotic Paradox, explaining how bacteria are becoming resistant to nearly all known antibiotics. The author of the book, Stuart Levy, has argued that medicine and public health would be much better off if medical students were taught as much about Darwin as they are about Pasteur.

Huh? Why should doctors learn so much about Darwin? Because bacteria evolve under pressure from natural selection—just as Darwin proposed. Once humans made antibiotics part of the environment, bacteria evolved resistance to those drugs.

Darwin’s theory of evolution has been described as “the most important scientific idea that anyone has ever had.” Ever since Darwin, new branches of science have appeared and matured, gathering information about the living world beyond Darwin’s wildest dreams. Any of that evidence—from biochemistry, molecular genetics, geology, and physics—could have confirmed or negated Darwin’s work. Astonishingly, all those new data supported, strengthened, and expanded Darwin’s insights. Evolutionary theory now informs every aspect of biological thought, from global ecology to medicine.

But, evolutionary theory does more than just describe these phenomena; it enables us to predict how organisms will respond to events around them. Evolutionary theory informs new treatments for AIDS, new approaches to the production and use of antibiotics, and new strategies for using insecticides. These and other applications explain why understanding evolution is vital to making informed judgments about many issues in the modern world.

The goal of this unit is to help students understand the evolutionary worldview. As scientists and teachers, we believe very strongly that the purpose of education is to promote understanding, not to compel belief. That applies to evolution, too, which, if properly taught, should never threaten the beliefs of students. As biologists, we genuinely feel, as Darwin wrote, “There is grandeur in this view of life . . . .” We hope you agree.
Darwin’s Theory of Evolution

CHAPTER 16

Understanding by Design

Chapter 16 introduces students to the Unit 5 Enduring Understanding: The diversity of life is the result of ongoing evolutionary change. Species alive today have evolved from ancient common ancestors. As the graphic organizer at the right shows, the chapter explains how Darwin developed his theory of evolution by natural selection. It describes his own observations while traveling aboard the Beagle, other influences on his thinking, and the main lines of evidence that support his theory.

PERFORMANCE GOALS

In Chapter 16, students will interpret visuals, analyze data, and apply concepts to demonstrate comprehension of the unit Enduring Understanding. At the end of the chapter, students will predict how a particular species might adapt to changes on Earth. They will also write an argument in support of evolution.

Connect to the Big Idea

Have students look at the photograph, and point out some of the ways the shells of the Cuban tree snails vary. Connect the image with the Big Idea of Evolution by explaining that the occurrence of natural variations such as these is a critical part of Charles Darwin’s theory of evolution by natural selection. Encourage students to anticipate the answer to the question, What is natural selection?

Ask students to read over the Chapter Mystery. Have a few students find online images of different species of Hawaiian honeycreepers and share them with the class. Explain that a bird’s beak suits the type of food it normally eats. Ask students to infer what type of food each pictured species eats. Connect the Chapter Mystery to the Big Idea of Evolution by stating that all these varied honeycreepers came about through evolution by natural selection.

Have students preview the chapter vocabulary terms using the Flash Cards.
SUCH VARIED HONEYCREEPERS

The misty rain forests on the Hawaiian island of Kauai are home to birds found nowhere else on Earth. Hiking at dawn, you hear them before you see them. Their songs fill the air with beautiful music. Then you spot a brilliant red bird with black wings called an ‘i’iwi. As you watch, it uses its long, curved beak to probe for nectar deep in the flowers of ‘ohi’a trees.

The ‘i’iwi is just one of a number of species of Hawaiian honeycreepers, all of which are related to finches. Various honeycreeper species feed on nectar, insects, seeds, or fruits. Many Hawaiian honeycreepers, however, feed only on the seeds or nectar of unique Hawaiian plants.

How did all these birds get to Hawaii? How did some of them come to have such specialized diets? As you read the chapter, look for clues that help explain the number and diversity of Hawaiian honeycreepers. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the honeycreepers mystery is only the beginning. Take a video field trip to Hawaii with the ecogeeks of Untamed Science to see where the mystery leads.

What’s Online

- Untamed Science Video
- Chapter Mystery

INSIDE:
- 16.1 Darwin’s Voyage of Discovery
- 16.2 Ideas That Shaped Darwin’s Thinking
- 16.3 Darwin Presents His Case
- 16.4 Evidence of Evolution

Darwin’s Theory of Evolution 449
Getting Started

Objectives

16.1.1 State Charles Darwin's contribution to science.
16.1.2 Describe the three patterns of biodiversity noted by Darwin.

Student Resources

Study Workbooks A and B, 16.1 Worksheets
Spanish Study Workbook, 16.1 Worksheets

Answers

IN YOUR NOTEBOOK Sample answer: When Earth changes, life forms need to adapt to new environmental conditions to survive.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES
II, IV

CONTENT
C.3.a, G.1, G.2, G.3

INQUIRY
A.1.b, A.2.a, A.2.b

Darwin’s Epic Journey

What was Charles Darwin’s contribution to science?

Charles Darwin was born in England on February 12, 1809—the same day as Abraham Lincoln. He grew up at a time when the scientific view of the natural world was shifting dramatically. Geologists were suggesting that Earth was ancient and had changed over time. Biologists were suggesting that life on Earth had also changed. The process of change over time is called evolution. Darwin developed a scientific theory of biological evolution that explains how modern organisms evolved over long periods of time through descent from common ancestors.

Darwin’s journey began in 1831, when he was invited to sail on the HMS Beagle’s five-year voyage along the route shown in Figure 16–1. The captain and his crew would be mapping the coastline of South America. Darwin planned to collect specimens of plants and animals. No one knew it, but this would be one of the most important scientific voyages in history. Why? Because the Beagle trip led Darwin to develop what has been called the single best idea anyone has ever had.

If you think evolution is just about explaining life’s ancient history, you might wonder why it’s so important. But Darwin’s work offers vital insights into today’s world by showing how the living world is constantly changing. That perspective helps us understand modern phenomena like drug-resistant bacteria and newly emerging diseases like avian flu.

THINK ABOUT IT If you’d met young Charles Darwin, you probably wouldn’t have guessed that his ideas would change the way we look at the world. As a boy, Darwin wasn’t a star student. He preferred bird-watching and reading for pleasure to studying. His father once complained, “You will be a disgrace to yourself and all your family.” Yet Charles would one day come up with one of the most important scientific theories of all time—becoming far from the disgrace his father feared he would be.
Observations Aboard the Beagle

What three patterns of biodiversity did Darwin note?

A collector of bugs and shells in his youth, Darwin had always been fascinated by biological diversity. On his voyage, the variety and number of different organisms he encountered dazzled him. In a single day’s trip into the Brazilian forest, he collected 68 species of beetles, and he wasn’t particularly looking for beetles!

Darwin filled his notebooks with observations about the characteristics and habitats of the different species he saw. But Darwin wasn’t content just to describe biological diversity. He wanted to explain it in a scientific way. He kept his eyes and mind open to larger patterns into which his observations might fit. As he traveled, Darwin noticed three distinctive patterns of biological diversity: (1) Species vary globally, (2) species vary locally, and (3) species vary over time.

Species Vary Globally Darwin visited a wide range of habitats on the continents of South America, Australia, and Africa and recorded his observations. For example, Darwin found flightless, ground-dwelling birds called rheas living in the grasslands of South America. Rheas look and act a lot like ostriches. Yet rheas live only in South America, and ostriches live only in Africa. When Darwin visited Australia’s grasslands, he found another large flightless bird, the emu.

Darwin noticed that different, yet ecologically similar, animal species inhabited separated, but ecologically similar, habitats around the globe.

Darwin also noticed that rabbits and other species living in European grasslands were missing from the grasslands of South America and Australia. What’s more, Australia’s grasslands were home to kangaroos and other animals that were found nowhere else. What did these patterns of geographic distribution mean? Why did different flightless birds live in similar grasslands across South America, Australia, and Africa, but not in the Northern Hemisphere? Why weren’t there rabbits in Australian habitats that seemed ideal for them? And why didn’t kangaroos live in England?

Darwin’s Voyage

1. Using a world map and Figure 16–1, count the number of lines of 10° latitude the Beagle crossed.

2. Using the biome map from Chapter 4 as a reference, identify three different biomes Darwin visited on his voyage.

Analyze and Conclude

1. Infer How did the geography of Darwin’s voyage give him far greater exposure to species variability than his fellow scientists back home had?

Figure 16–1 Darwin’s Voyage

On a five-year voyage aboard the Beagle, Charles Darwin visited several continents and many remote islands. Draw Conclusions Why is it significant that many of the stops the Beagle made were in tropical regions?

Teach

Build Science Skills

Discuss in greater detail the example of rheas, ostriches, and emus described in the text. Show the class visuals of the three types of birds and their habitats, and call on students to point out how the birds are adapted to their environments. Ask students to infer why large, flightless birds are found in grassland habitats around the globe.

Differentiated Instruction

L1 Special Needs Pair special needs students with other students in the class, and have special needs students trace Darwin’s voyage on the map in Figure 16–1 while their partners read aloud about the voyage. Then, ask partners to find visuals of some of the places and organisms that Darwin saw and use them to make a scrapbook of his voyage.

L2 Focus on ELL: Build Background

Begin intermediates and intermediate spearkers Guide students in using the visuals in the lesson to fill in a BKWL Chart about Darwin. Using the maps and photographs, summarize for students Darwin’s voyage and observations. Have them take notes in column B as you do. Then, tell them to make inferences about Darwin, based on their notes, and list them in column K. In column W, have them record any questions they have about Darwin. They can look for answers to their questions as they read the lesson, and then write the answers in column L.

Study Wkbks A/B, Appendix S27, BKWL Chart. Transparencies, G012.
LESSON 16.1

Teach continued

Use Visuals

Call on students to describe differences between the two tortoises shown in Figure 16–2. Discuss how the differences between the tortoises are related to the differences in their environments. Challenge students to infer, based on the discussion, why groups of islands like the Galápagos are good places to study evolution.

Ask What other groups of islands might be good places to study evolution? (Sample answers: the Hawaiian Islands, the islands of the Caribbean)

DIFFERENTIATED INSTRUCTION

Less Proficient Readers Suggest students use Cornell Notes to organize the information pertaining to Darwin’s observations. Tell them to include as key words any terms that pertain to the main ideas, not just the lesson vocabulary terms.

Study Wkbks A/B, Appendix S22, Cornell Notes. Transparencies, G05.

Advanced Students Have students obtain a copy of Darwin’s book, On the Origin of Species, and find passages in which Darwin describes his observations of plants and animals on the Galápagos Islands. Ask them to put some of the observations in their own words and share them with the class in an oral report. Have them illustrate their report with copies of Darwin’s original drawings.

Students may say that the varied habitats on the Hawaiian Islands required honeycreepers to exploit different food sources, depending on which island they inhabited. This, in turn, may have led to the evolution of different traits on different islands. Students can go online to Biology.com to gather their evidence.

Species Vary Locally There were other puzzles, too. For example, Darwin found two species of rheas living in South America. One lived in Argentina’s grasslands and the other in the colder, harsher grass and scrubland to the south. Darwin noticed that different, yet related, animal species often occupied different habitats within a local area.

Other examples of local variation came from the Galápagos Islands. About 1000 km off the Pacific coast of South America. These islands are close to one another, yet they have different ecological conditions. Several islands were home to distinct forms of giant land tortoises. Darwin saw differences among the tortoises but didn’t think much about them. In fact, like other travelers, Darwin ate several tortoises and tossed their remains overboard without studying them closely! Then Darwin learned from the islands’ governor that the tortoises’ shells varied in predictable ways from one island to another, as shown in Figure 16–2. Someone who knew the animals well could identify which island an individual tortoise came from, just by looking at its shell.

Darwin also observed that different islands had different varieties of mockingbirds, all which resembled mockingbirds that Darwin had seen in South America. Darwin also noticed several types of small brown birds on the islands with beaks of different shapes. He thought that some were wrens, some were warblers, and some were blackbirds. He didn’t consider these smaller birds to be unusual or important—at first.

Species Vary Over Time In addition to collecting specimens of living species, Darwin also collected fossils, which scientists already knew to be the preserved remains or traces of ancient organisms. Some fossils didn’t look anything like living organisms, but others did.

Mystery Clue

Like the small brown birds on the Galápagos, Hawaiian honeycreepers live on islands with slightly different habitats. How might these varied habitats have affected the evolution of honeycreeper species?

Check for Understanding

ONE-MINUTE RESPONSE

Ask students to write a one-minute response to the following:

Contrast the pattern Darwin observed among the large, flightless birds and the pattern he observed among the tortoises. (The large, flightless birds lived far apart, yet their environments were similar, and the birds looked similar. The tortoises lived close to one another, yet they had differences that seemed to correspond to differences in their environments.)

ADJUST INSTRUCTION

Call on volunteers to read their response aloud. If students have trouble distinguishing these patterns, tell them that similar environments seem to result in similarities among organisms. Different environments seem to result in differences among organisms.
Darwin noticed that some fossils of extinct animals were similar to living species. One set of fossils unearthed by Darwin belonged to the long-extinct glyptodont, a giant armored animal. Currently living in the same area was a similar animal, the armadillo. You can see in Figure 16–3 that the armadillo appears to be a smaller version of the glyptodont. Darwin said of the organisms: “This wonderful relationship in the same continent between the dead and the living, will, I do not doubt, hereafter throw more light on the appearance of organic beings on our earth, and their disappearance from it, than any other class of facts.” So, why had glyptodonts disappeared? And why did they resemble armadillos?

Putting the Pieces of the Puzzle Together On the voyage home, Darwin thought about the patterns he’d seen. The plant and animal specimens he sent to experts for identification set the scientific community buzzing. The Galápagos mockingbirds turned out to belong to three separate species found nowhere else! And the little brown birds that Darwin thought were wrens, warblers, and blackbirds were actually all species of finches! They, too, were found nowhere else, though they resembled a South American finch species. The same was true of Galápagos tortoises, marine iguanas, and many plants that Darwin collected on the islands.

Darwin was stunned by these discoveries. He began to wonder whether different Galápagos species might have evolved from South American ancestors. He spent years actively researching and filling notebooks with ideas about species and evolution. The evidence suggested that species are not fixed and that they could change by some natural process.

Assess and RemEDIATE

EVALUATE UNDERSTANDING
Ask students to write four fill-in, true-false, or multiple-choice questions based on the Key Concepts in the lesson. Have them exchange questions with a partner and try to answer the partner’s questions. Then, have students complete the 16.1 Assessment.

REMEDICATION SUGGESTION
Struggling Students If students have difficulty with Question 3, suggest they review biotic and abiotic factors in Chapter 3.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. The process of change over time

1b. Geologists were suggesting that Earth was ancient and had changed over time. Biologists were suggesting that life on Earth had changed over time, as well. These ideas might have influenced Darwin to develop a theory about how organisms had changed over long periods of time.

2a. Darwin observed that organisms vary globally, locally, and over time.

2b. Sample answer: This finding might have helped him understand that many species go extinct, while others evolve into different species. Darwin might have inferred that Earth’s current diversity is less than the total diversity of living things that have ever existed.

3a. Sample answer: Biotic factors are any living component of the environment with which individuals interact, such as the plants they eat for food or the predators they try to avoid. Abiotic factors are nonliving parts of an organism’s environment, such as precipitation and soil type. Variation in abiotic and biotic factors on different Galápagos Islands might explain the different traits of tortoises on the islands. For example, Hood Island is dry and has sparse vegetation, whereas Isabela Island is rainy and has dense vegetation. The necks and shells of tortoises suit them for the abiotic and biotic factors on the particular island they inhabit.
Getting Started

Objectives
16.2.1 Identify the conclusions drawn by Hutton and Lyell about Earth’s history.  
16.2.2 Describe Lamarck’s hypothesis of evolution.  
16.2.3 Describe Malthus’s view of population growth.  
16.2.4 Explain the role of inherited variation in artificial selection.

Student Resources
Study Workbooks A and B, 16.2 Worksheets  
Spanish Study Workbook, 16.2 Worksheets  
Lesson Overview • Lesson Notes  
Activities: Art in Motion • Assessment: Self-Test, Lesson Assessment

Build Background
Describe a husband and wife who exercise regularly at the gym, build up their muscles, and then later have a baby. Ask students if the big muscles of the parents will be passed on to their child. (Students are likely to say no.) Tell them an early nineteenth-century scientist named Lamarck thought traits organisms developed during their life could be passed on to their offspring. Explain that they will read about Lamarck in this lesson, because his ideas influenced Darwin.

Teach for Understanding

THINK ABOUT IT All scientists are influenced by the work of other scientists, and Darwin was no exception. The Beagle’s voyage came during one of the most exciting periods in the history of science. Geologists, studying the structure and history of Earth, were making new observations about the forces that shape our planet. Naturalists were investigating connections between organisms and their environments. These and other new ways of thinking about the natural world provided the foundation on which Darwin built his ideas.

An Ancient, Changing Earth

What did Hutton and Lyell conclude about Earth’s history?  
Many Europeans in Darwin’s day believed Earth was only a few thousand years old, and that it hadn’t changed much. By Darwin’s time, however, the relatively new science of geology was providing evidence to support different ideas about Earth’s history. Most famously, geologists James Hutton and Charles Lyell formed important hypotheses based on the work of other researchers and on evidence they uncovered themselves. Hutton and Lyell concluded that Earth is extremely old and that the processes that changed Earth in the past are the same processes that operate in the present. In 1785, Hutton presented his hypotheses about how geological processes have shaped the Earth. Lyell, who built on the work of Hutton and others, published the first volume of his great work, Principles of Geology, in 1830.

FIGURE 16–4 Ancient Rocks  
These rock layers in the Grand Canyon were laid down over millions of years and were then slowly washed away by the river, forming a channel.
Hutton also proposed that forces beneath Earth’s surface can push rock layers upward, tilting or twisting them in the process. Over long periods, those forces can build mountain ranges. Mountains, in turn, can be worn down by rain, wind, heat, and cold. Most of these processes operate very slowly. For these processes to have produced Earth as we know it, Hutton concluded that our planet must be much older than a few thousand years. He introduced a concept called deep time—the idea that our planet’s history stretches back over a period of time so long that it is difficult for the human mind to imagine—to explain his reasoning.

Lyell’s Principles of Geology Lyell argued that laws of nature are constant over time and that scientists must explain past events in terms of processes they can observe in the present. This way of thinking, called uniformitarianism, holds that the geological processes we see in action today must be the same ones that shaped Earth millions of years ago. Ancient volcanoes released lava and gases, just as volcanoes do now. Ancient rivers slowly dug channels, like the one in Figure 16–5, and carved canyons in the past, just as they do today. Lyell’s theories, like those of Hutton before him, relied on there being enough time in Earth’s history for these changes to take place. Like Hutton, Lyell argued that Earth was much, much older than a few thousand years. Otherwise, how would a river have enough time to carve out a valley?

Darwin had begun to read Lyell’s books during the voyage of the Beagle, which was lucky. Lyell’s work helped Darwin appreciate the significance of an earthquake he witnessed in South America. The quake was so strong that it threw Darwin onto the ground. It also lifted a stretch of rocky shoreline more than 3 meters out of the sea—with mussels and other sea animals clinging to it. Sometime later, Darwin observed fossils of marine animals in mountains thousands of feet above sea level.

Those experiences amazed Darwin and his companions. But only Darwin turned them into a startling scientific insight. He realized that he had seen evidence that Lyell was correct! Geological events like the earthquake, repeated many times over many years, could build South America’s Andes Mountains—a few feet at a time. Rocks that had once been beneath the sea could be pushed up into mountains. Darwin asked himself, If Earth can change over time, could life change too?

Darwin observed fossils of marine animals clinging to rocks in the Simeto River. Among them is a deep channel, labeled “B,” carved into a bed of lava. The channel, shown in the photo, was formed gradually by the movement of water in the Simeto River.

**Teach**

**Connect to Geology**

Have students examine the photographs shown in Figures 16–4 and 16–5. Point out that there is running water in both photographs. Call on volunteers to infer how geological processes produced the Grand Canyon and the deep channel of the Simeto River in Italy. (Moving water gradually eroded rock layers.) Discuss how long it took the Grand Canyon to form. (Geologists estimate that the Grand Canyon formed over 6 million years.) Ask students to infer how knowledge of such processes influenced Darwin.

**DIFFERENTIATED INSTRUCTION**

**Less Proficient Readers** Give students one minute to write down everything they know about geology. Then, ask students to review An Ancient, Changing Earth. As they read, students should add details from the text to their brainstorm sheet.

**Focus on ELL:** Extend Language

**ADVANCED AND ADVANCED HIGH SPEAKERS**

As students read the lesson, have them write their own definition of each of the following concepts, based on the information in the text: geological change, uniformitarianism, inheritance of acquired characteristics, population growth, and artificial selection. When you review the lesson, ask students to read their definitions to the class.

**How Science Works**

**PATRICK MATTHEW AND HIS THEORY OF EVOLUTION**

Most people have heard of Charles Darwin’s theory of evolution by natural selection, but how many people have heard of Patrick Matthew’s theory of evolution? Very few, although Matthew thought his name should be associated with the theory of evolution, not Charles Darwin’s. Matthew was born in 1790 in Scotland, where he lived most of his life. He owned and managed a large fruit orchard. Although he wasn’t a scientist, he wrote about evolution and described a mechanism similar to what we today call natural selection. Matthew’s work appeared almost 30 years before Darwin published On the Origin of Species. Did Darwin steal Matthew’s ideas? It seems unlikely, because Matthew’s theories were “hidden” in obscure publications that Darwin claimed never to have read. Matthew’s theory also differed from Darwin’s in several important ways. It should also be noted that Matthew, unlike Darwin, did not spend decades gathering evidence for his theory.
LESSON 16.2

Teach continued

Build Science Skills
Challenge small groups of students to design an experiment to test Lamarck’s hypothesis that acquired characteristics can be passed from parents to offspring. Their experimental design should include a hypothesis, a procedure, possible outcomes, and an explanation of how the outcomes would or would not support their hypothesis. Give groups a chance to share their experimental designs.

DIFFERENTIATED INSTRUCTION

L3 Advanced Students Suggest students research the ideas of Georges Cuvier and Georges-Louis Leclerc, Comte de Buffon—two naturalists whose ideas preceded Darwin’s. Have students prepare a 5-to 10-minute class presentation in which they summarize the work of these two men and suggest how their work may have influenced Darwin.

Address Misconceptions

Selection for Perfection A common student misconception is that evolution produces perfect organisms. In the next lesson, this is addressed in detail, but take the opportunity here to introduce this misconception. Explain that the tendency toward perfection is one of the great flaws of Lamarck’s ideas. No organism is perfectly adapted. In fact, the variations that make us less than perfect may also save us if our environment changes.

FIGURE 16–6 Acquired Characteristics? According to Lamarck, this black-necked stilt’s long legs were the result of the bird’s innate tendency toward perfection. He claimed that if a water bird needed long legs to wade in deeper water, it could acquire them by making an effort to stretch and use its legs in new ways. He also claimed that the bird could then pass the trait on to its offspring.

Lamarck’s Evolutionary Hypotheses

How did Lamarck propose that species evolve?
Darwin wasn’t the first scientist to suggest that characteristics of species could change over time. Throughout the eighteenth century, a growing fossil record supported the idea that life somehow evolved. Ideas differed, however, about just how life evolved. The French naturalist Jean-Baptiste Lamarck proposed two of the first hypotheses. Lamarck suggested that organisms could change during their lifetimes by selectively using or not using various parts of their bodies. He also suggested that individuals could pass these acquired traits on to their offspring, enabling species to change over time. Lamarck published his ideas in 1809, the year Darwin was born.

Lamarck’s Ideas Lamarck proposed that all organisms have an inborn urge to become more complex and perfect. As a result, organisms change and acquire features that help them live more successfully in their environments. He thought that organisms could change the size or shape of their organs by using their bodies in new ways. According to Lamarck, for example, a water bird could have acquired long legs because it began to wade in deeper water looking for food. As the bird tried to stay above the water’s surface, its legs would grow a little longer. Structures of individual organisms could also change if they were not used. If a bird stopped using its wings to fly, for example, its wings would become smaller. Traits altered by an individual organism during its life are called acquired characteristics.

Lamarck also suggested that a bird that acquired a trait, like longer legs, during its lifetime could pass that trait on to its offspring, a principle referred to as inheritance of acquired characteristics. Thus, over a few generations, birds like the one in Figure 16–6 could evolve longer and longer legs.

Evaluating Lamarck’s Hypotheses Today, we know that Lamarck’s hypotheses were incorrect in several ways. For one thing, organisms don’t have an inborn drive to become more perfect. Evolution does not mean that over time a species becomes “better” somehow, and evolution does not progress in a predetermined direction. We now also know that traits acquired by individuals during their lifetime cannot be passed on to offspring. However, Lamarck was one of the first naturalists to suggest that species are not fixed. He was among the first to try to explain evolution scientifically using natural processes. He also recognized that there is a link between an organism’s environment and its body structures. So, although Lamarck’s explanation of evolutionary change was wrong, his work paved the way for later biologists, including Darwin.

In Your Notebook Why are Lamarck’s ideas called scientific hypotheses and not scientific theories?

Check for Understanding

DEPTH OF UNDERSTANDING
Ask students to respond in writing to the following question: How did Lamarck influence Darwin’s thinking? (Students with a superficial understanding might respond incorrectly that Lamarck gave Darwin the idea that individuals could develop new traits during their life and pass them to their offspring. Students with a sophisticated understanding should respond that Lamarck influenced Darwin with his ideas that natural processes can explain evolution and that species are influenced by their environments.)

ADJUST INSTRUCTION
Collect and read students’ responses. Select several of the more sophisticated responses, and share them with the class. To ensure understanding, ask a few students to rephrase various answers.

Answers

IN YOUR NOTEBOOK Hypotheses, unlike theories, are statements that are not necessarily supported by evidence, and Lamarck’s ideas were not supported by evidence.

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Population Growth

What was Malthus’s view of population growth?

In 1798, English economist Thomas Malthus noted that humans were being born faster than people were dying, causing overcrowding, as shown in Figure 16–7. Malthus reasoned that if the human population grew unchecked, there wouldn’t be enough living space and food for everyone. The forces that work against population growth, Malthus suggested, include war, famine, and disease.

Darwin realized that Malthus’s reasoning applied even more to other organisms than it did to humans. A maple tree can produce thousands of seeds each summer. One oyster can produce millions of eggs each year. If all the descendants of almost any species survived for several generations, they would overrun the world. Obviously, this doesn’t happen. Most offspring die before reaching maturity, and only a few of those that survive manage to reproduce.

Why was this realization so important? Darwin had become convinced that species evolved. But he needed a mechanism—a scientific explanation based on a natural process—to explain how and why evolution occurred. When Darwin realized that most organisms don’t survive and reproduce, he wondered which individuals survive … and why.

Artificial Selection

How is inherited variation used in artificial selection?

To find an explanation for change in nature, Darwin studied change produced by plant and animal breeders. Those breeders knew that individual organisms vary—that some plants bear larger or smaller fruit than average for their species, that some cows give more or less milk than others in their herd. They told Darwin that some of this variation could be passed from parents to offspring and used to improve crops and livestock.

Quick Lab

Variation in Peppers

1. Obtain a green, yellow, red, or purple bell pepper.
2. Slice open the pepper and count the number of seeds it contains.
3. Compare your data with the data of other students who have peppers of a different color.

Analyze and Conclude

1. Calculate Find the average (mean) number of seeds in your class’s peppers. Then determine by how much the number of seeds in each pepper differs from the mean number.
2. Pose Questions Think of the kinds of variations among organisms that Darwin observed. If Darwin had seen your data, what questions might he have asked?

Quick Lab

PURPOSE Students will analyze variation in traits and infer questions Darwin might have posed about the data.

MATERIALS bell peppers of different colors, knife

SAFETY Remind students to wear goggles and handle the knife carefully. Make sure they wash their hands after finishing the lab.

PLANNING Provide each student with a pepper. Use several colors of peppers if possible. Be sure to use bell peppers, not hot peppers.

ANALYZE AND CONCLUDE

1. Answers will vary depending on class data.
2. Sample answer: Darwin might have asked whether variation in seed number was associated with other variables, such as growth conditions or pepper color. He may have wondered if the variation correlated to a pepper color’s success in its environment.

Connect to Math

Malthus believed populations of organisms increase exponentially, while the resources they need increase linearly. Tell students that his model of population growth can be expressed by the equation:

\[ P_n = (1 + r)^n P_0 \]

where \( n \) = number of years, \( r \) = rate of population growth per year, \( P_0 \) = size of the original population, and \( P_n \) = size of the population after \( n \) years. Starting with \( n = 0 \) and \( P_0 = 100 \), and assuming that \( r \) is constant at 0.2, work with students to find the values of \( P_n \) for \( n = 1 \) to 10. Then, have them graph the values. They should plot the values of \( n \) on the \( x \)-axis and the corresponding values of \( P_n \) on the \( y \)-axis. (Their graphs should resemble a parabola.)

On the same graph, ask them to draw a straight line passing from the origin to the right at a 45° angle (i.e., a graph of \( y = x \)). Tell them this line represents a linear increase in resources. Discuss how and why the line representing population differs from the line representing resources. Also, discuss the implications of the lines for real populations.

DIFFERENTIATED INSTRUCTION

English Language Learners After students have finished reading the lesson, have them get together for a Core Concept Discussion. Each student in the group should contribute one core concept from the lesson (such as Lamarck’s ideas or Hutton and Lyell’s conclusions), then other group members take turns discussing it.

Study Wkbks A/B, Appendix S3, Core Concept Discussion.

Answers

FIGURE 16–7 There wouldn’t be enough living space and food for everyone, which might increase the chances of war, famine, disease, and other population-limiting phenomena.
Assess and Remediate

EVALUATE UNDERSTANDING
Have students make an acrostic based on Darwin. Each letter in the term should be the first letter in a sentence describing an influence on Darwin. Then, have students complete the 16.2 Assessment.

REMEDIATION SUGGESTION

Struggling Students If students have trouble with Question 4b, suggest they reread the Key Concept about artificial selection.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. Hutton thought geological processes, such as mountain building, take a very long time, so Earth must be much older than most people believed. Lyell expanded on Hutton’s idea by suggesting that the same geological processes that changed Earth in the past are still at work today.

1b. Hutton and Lyell would explain that the Grand Canyon formed over millions of years as the running water of the Colorado River gradually wore away rocks—just as it does today.

2a. An acquired characteristic is a trait altered during an organism’s life. Lamarck thought acquired characteristics could be passed on to offspring.

2b. Lamarck’s idea about the inheritance of acquired characteristics and an organism’s tendency toward perfection have been proven wrong. However, he was right that species are not fixed but change in response to their environment.

3a. living space and food

3b. Malthus got Darwin thinking about overproduction of offspring. The idea that many more organisms are produced than can survive led Darwin to suggest a mechanism that explains which organisms survive to reproduce.

4a. the process of allowing only organisms with desirable traits to reproduce in order to increase the number of individuals with those traits

4b. No, there would be nothing to select if all the members of a species were identical.

WRITE ABOUT SCIENCE

5. Answers will vary but should show that students understand Malthus’s ideas about population growth and its potential negative consequences, such as war and disease.
**Teach**

**Lead a Discussion**

By the end of Lesson 16.2, students should be familiar with all of the individuals in the time line except for Alfred Russel Wallace. You may want to provide additional background on him. (See Quick Facts below.) Tell students Wallace’s letter influenced Darwin to publish *On the Origin of Species* more quickly than he otherwise would have. Discuss how the social climate of Darwin’s time made him reluctant to publish his ideas about evolution and why he needed the extra impetus from Wallace to publish them when he did.

**DIFFERENTIATED INSTRUCTION**

**ELL English Language Learners**  Match beginning or intermediate speakers with more advanced speakers, and ask pairs to discuss how each individual in the time line influenced Darwin to develop his theory of evolution by natural selection. Then, have partners collaborate to write a sentence about each individual that states the nature of his influence.

**Answers**

**WRITING** Dialogues will vary but should include similar statements by Darwin and Wallace about how plants and animals vary and how they evolve by natural selection. Dialogues should also reveal the two men’s similar experiences as naturalists.

**Quick Facts**

**ALFRED RUSSEL WALLACE**

Alfred Russel Wallace is best remembered for developing a theory of evolution that is very similar to that of Darwin. However, this is just one reason why, by 1900, Wallace was among the world’s most widely known and well-respected scientists. Other reasons include Wallace’s concept of polymorphism and early contributions to the understanding of mimicry. Further, he authored the most famous book ever written on the Malay Archipelago and established himself as the world’s authority on Indonesia. In addition, he discovered the “Wallace Effect” (selection for reproductive isolation). Throughout his life, Wallace defended natural selection while developing his own ideas—many of which were cited in Darwin’s own works. In fact, historians believe the two men greatly influenced and challenged each other.
Darwin Presents His Case

Key Questions
- Under what conditions does natural selection occur?
- What does Darwin’s mechanism for evolution suggest about living and extinct species?

Vocabulary
adaptation
fitness
natural selection

Evolution by Natural Selection

Under what conditions does natural selection occur?

Darwin’s great contribution was to describe a process in nature—a scientific mechanism—that could operate like artificial selection. In On the Origin of Species, he combined his own thoughts with ideas from Malthus and Lamarck.

The Struggle for Existence
After reading Malthus, Darwin realized that if more individuals are produced than can survive, members of a population must compete to obtain food, living space, and other limited necessities of life. Darwin described this as the struggle for existence.

But which individuals come out on top in this struggle?

Variation and Adaptation
Here’s where individual variation plays a vital role. Darwin knew that individuals have natural variations among their heritable traits. He hypothesized that some of those variants are better suited to life in their environment than others. Members of a predatory species that are faster or have longer claws or sharper teeth can catch more prey. And members of a prey species that are faster or better camouflaged can avoid being caught.

THINK ABOUT IT
Soon after reading Malthus and thinking about artificial selection, Darwin worked out the main points of his theory about natural selection. Most of his scientific friends considered Darwin’s arguments to be brilliant, and they urged him to publish them. But although he wrote up a complete draft of his ideas, he put the work aside and didn’t publish it for another 20 years. Why? Darwin knew that many scientists, including some of Darwin’s own teachers, had ridiculed Lamarck’s ideas. Darwin also knew that his own theory was just as radical, so he wanted to gather as much evidence as he could to support his ideas before he made them public.

Then, in 1858, Darwin reviewed an essay by Alfred Russel Wallace, an English naturalist working in Malaysia. Wallace’s thoughts about evolution were almost identical to Darwin’s! Not wanting to get “scooped,” Darwin decided to move forward with his own work. Wallace’s essay was presented together with some of Darwin’s observations at a scientific meeting in 1858. The next year, Darwin published his first complete work on evolution: On the Origin of Species.
Any heritable characteristic that increases an organism’s ability to survive and reproduce in its environment is called an adaptation. Adaptations can involve body parts or structures, like a tiger’s claws; colors, like those that make camouflage or mimicry possible; or physiological functions, like the way a plant carries out photosynthesis. Many adaptations also involve behaviors, such as the complex avoidance strategies prey species use. Examples of adaptations are shown in Figure 16–9.

**Survival of the Fittest** Darwin, like Lamarck, recognized that there must be a connection between the way an organism “makes a living” and the environment in which it lives. According to Darwin, differences in adaptations affect an individual’s fitness. **Fitness** describes how well an organism can survive and reproduce in its environment.

Individuals with adaptations that are well suited to their environment can survive and reproduce and are said to have high fitness. Individuals with characteristics that are not well suited to their environment either die without reproducing or leave few offspring and are said to have low fitness. This difference in rates of survival and reproduction is called survival of the fittest. Note that **survival** here means more than just staying alive. In evolutionary terms, **survival** means reproducing and passing adaptations on to the next generation.

**In Your Notebook** If an organism produces many offspring, but none of them reach maturity, do you think the organism has high or low fitness? Explain your answer.

**Build Vocabulary**

**RELATED WORD FORMS** The verb **inherited** and the adjective **heritable** are related word forms. Inherited traits are passed on to offspring from their parents. They are described as heritable (or sometimes inheritable) characteristics.

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**Teach**

**Expand Vocabulary**

Make sure students understand the terms **adaptation** and **fitness**, because these terms are basic to their comprehension of the process of natural selection. After students read about the terms in context on this page, have them apply the concepts to specific cases. Ask them to describe examples of adaptations and explain how they increase the fitness of the organisms in which they occur.

**Differentiated Instruction**

**Less Proficient Readers** Suggest students make an outline of the lesson, using the green headings for the main topics and the blue headings for the subtopics. As they read the lesson, they can add details to their outline.

**Call on students to identify each adaptation shown in Figure 16–9. Discuss how adaptations increase an individual’s fitness. Describe additional examples of the same types of adaptations, such as viceroy butterflies that mimic poisonous monarch butterflies, stick insects that use camouflage to blend in with twigs, and dogs that growl defensively to warn off strangers. Then, challenge students to think of other types of adaptations that help organisms survive.**

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**How Science Works**

**Stephen Jay Gould and the Panda’s Thumb**

Few scientists have reached as wide an audience on the subject of evolution as paleontologist Stephen Jay Gould. His essays appeared in 300 consecutive issues of *Natural History* between 1974 and 2001, and his award-winning books have sold more than a million copies. He was fond of describing “jury-rigged” adaptations as examples that defy intelligent design. For example, the giant panda has a modified wrist bone that it uses as a thumb to grasp bamboo. “The . . . thumb wins no prize in an engineer’s derby,” Gould said, “but it does its job and excites our imagination all the more because it builds on such improbable foundations.” Along with his colleague Niles Eldredge, Gould also developed the theory of punctuated equilibrium, which posits that evolution often occurs in bursts of rapid change interspersed with long periods of little change.

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**Answers**

**In Your Notebook** If an organism produces many offspring, but none of them reach maturity, then it has low fitness, because its offspring will not pass on their traits to the next generation.
The Struggle for Existence
Organisms produce more offspring than can survive. Grasshoppers can lay over 200 eggs at a time. Only a small fraction of these offspring survive to reproduce.

Variation and Adaptation
There is variation in nature, and certain heritable variations—called adaptations—increase an individual's chance of surviving and reproducing. In this population of grasshoppers, heritable variation includes yellow and green body color. Green coloration is an adaptation: Green grasshoppers blend into their environment and so are less visible to predators.

Survival of the Fittest
Because their green color serves to camouflage them from predators, green grasshoppers have a higher fitness than yellow grasshoppers. This means that green grasshoppers survive and reproduce more often than do yellow grasshoppers in this environment.

Natural Selection
Green grasshoppers become more common than yellow grasshoppers in this population over time because: (1) more grasshoppers are born than can survive, (2) individuals vary in color and color is a heritable trait, and (3) green individuals have a higher fitness in their current environment.

Address Misconceptions
Rate of Evolution
Students commonly have the misconception that challenges to Darwin's view of evolution as a slow, steady process mean that natural selection is no longer accepted by scientists. Make sure students understand that evolution by natural selection is not in dispute. Rather, it has just been extended to include the possibility of evolution occurring at a relatively rapid rate under certain conditions. (See note about Stephen Jay Gould on preceding page.) In other words, Darwin's theory has been modified and improved, but his basic principles remain unchallenged within the scientific community.

Quick Facts
OBSERVING NATURAL SELECTION
A recent article published in the journal Science documents a case of selection at work in a natural population. The study not only adds support to Darwin's theory of evolution by natural selection, it also demonstrates that natural selection can occur very rapidly when selective pressures are especially strong. The study focused on a species of Samoan butterfly. The butterflies were infected with bacteria that killed males before they hatched. Although females were not affected by the bacteria, the almost total decimation of males threatened the entire population. Then, a mutation occurred (or was introduced) that gave males the ability to resist the bacteria and survive. Within just one year, or ten generations, the percentage of males in the butterfly population increased from a mere 1 percent to almost 40 percent, and all of the surviving males had the mutation. The researchers noted that this may be the fastest evolutionary change ever observed.
Natural Selection  Darwin named his mechanism for evolution *natural selection* because of its similarities to artificial selection. *Natural selection* is the process by which organisms with variations most suited to their local environment survive and leave more offspring. In both artificial and natural selection, only certain individuals in a population produce new individuals. But in natural selection, the environment—not a farmer or animal breeder—influences fitness.

When does natural selection occur? Natural selection occurs in any situation in which more individuals are born than can survive (the struggle for existence), there is natural heritable variation (variation and adaptation), and there is variable fitness among individuals (survival of the fittest). Well-adapted individuals survive and reproduce. From generation to generation, populations continue to change as they become better adapted, or as their environment changes. Figure 16–10 uses a hypothetical example to show the process of natural selection. Notice that natural selection acts only on inherited traits because those are the only characteristics that parents can pass on to their offspring.

Natural selection does not make organisms “better.” Adaptations don’t have to be perfect—just good enough to enable an organism to pass its genes to the next generation. Natural selection also doesn’t move in a fixed direction. There is no one, perfect way of doing something, as demonstrated by Figure 16–11. Natural selection is simply a process that enables species to survive and reproduce in a local environment. If local environmental conditions change, some traits that were once adaptive may no longer be useful, and different traits may become adaptive. And if environmental conditions change faster than a species can adapt to those changes, the species may become extinct. Of course, natural selection is not the only mechanism driving evolution. You will learn about other evolutionary mechanisms in the next chapter.

**In Your Notebook** Give at least two reasons why the following statement is NOT true: “The goal of natural selection is to produce perfect organisms.”

![Figure 16–10](image)

**Check for Understanding**

**QUESTION BOX**

Evolution by natural selection is one of the central organizing concepts in biology—it is also one of the most commonly misunderstood. Establish a secure box in your classroom where students can leave anonymous questions. As an assignment, have everyone in the class write at least one question.

**ADJUST INSTRUCTION**

Collect and review students’ questions regularly. Go over the questions with the class. If an important question does not get asked, take the opportunity to raise it. Be sure to cover the common misconception that organisms evolve traits for a purpose as in, “birds evolved wings to fly.” That is not correct. Rather, birds have wings that, today, enable them to fly.

**Build Science Skills**

Point out the two different styles of pollination pictured in Figure 16–11. Have students look closely at the flowers and describe any structures that might be adaptations for pollination. (Sample answer: The brightly colored blossoms of the apple tree flowers might be an adaptation that attracts insects.) Ask students to explain how natural selection led to these adaptations. Use their answers to start a general discussion of why reproductive traits such as these are under strong selective pressure.

**DIFFERENTIATED INSTRUCTION**

**ELL** Struggling Students  Point out that Darwin called his mechanism for evolution by the term *natural selection* because the process resembles artificial selection. Make sure students understand the similarities and differences between artificial and natural selection. Have them complete a Venn Diagram that compares and contrasts the two processes.

**Study Wkbks A/B, Appendix S33, Venn Diagram. Transparencies, GO18.**

**Focus on ELL: Extend Language**

**BEGINNING AND INTERMEDIATE SPEAKERS**

Assign each of three groups of students one of the terms adaptation, fitness, or selection. Give group members a large sheet of paper, and have them write the assigned term, its component parts, and its definition. Also have them make a drawing to illustrate the term. When groups finish, ask them to present their work to the class, and then post their work in a Word Wall.

**Study Wkbks A/B, Appendix S17, Word Wall.**

Sample answer: Honeycreepers faced different environmental pressures depending on which island they inhabited, so different traits would have been selected for on different islands. This would explain how different species of honeycreepers evolved. Students can go online to Biology.com to gather their evidence.

**Answers**

**IN YOUR NOTEBOOK** Sample answer: Because natural selection is a natural process, it cannot have goals. Further, natural selection could never produce “perfect” organisms because environments change, and no organism is “better” or “more perfect” than any other in adjusting to future changes.
Address Misconceptions

Natural Selection and Evolution Natural selection and evolution are often used interchangeably—but they are not the same thing. Natural selection is a mechanism of evolution. Make sure students understand that organisms can evolve in other ways, too—through random mutation, lateral gene transfer, genetic drift, and gene shuffling in sexual reproduction.

Assess and Remediate

EVALUATE UNDERSTANDING

Ask students to write definitions, in their own words, for the lesson vocabulary terms. Tell them to read their definitions to a partner, and have the partner identify the terms from the definitions. Then, have students complete the 16.3 Assessment.

REMEDIATION SUGGESTION

ELL English Language Learners If students have trouble with Question 1b, make sure they understand that the term fitness has a different meaning in the context of natural selection than it does in common usage. In biology, fitness is a measure of an organism’s ability to produce offspring as well as to survive.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. Natural selection is the process by which organisms with variations most suited to their environment (adaptations) survive and leave more offspring than individuals without the adaptations.

1b. Individuals with high fitness have adaptations that make them better suited for their environment, so they survive and reproduce more often than individuals who are less fit.

1c. In both artificial and natural selection, certain individuals in a population disproportionately pass on their traits to the next generation, resulting in changes to the population. However, in natural selection the environment—not a farmer or animal breeder—determines which individuals pass on their traits.

2a. Hutton and Lyell thought Earth was very old. This was important to Darwin, because it allowed enough time for natural selection to work.

2b. Evolutionary trees show ancestor-descendant relationships among groups of related organisms. A tree of life implies that all species living and extinct are descended from ancient common ancestors.

Common Descent

What does Darwin’s mechanism for evolution suggest about living and extinct species?

Natural selection depends on the ability of organisms to reproduce, which means to leave descendants. Every organism alive today is descended from parents who survived and reproduced. Those parents descended from their parents, and so forth back through time.

Just as well-adapted individuals in a species survive and reproduce, well-adapted species survive over time. Darwin proposed that, over many generations, adaptation could cause successful species to evolve into new species. He also proposed that living species are descended, with modification, from common ancestors—an idea called descent with modification. Notice that this aspect of Darwin’s theory implies that life has been on Earth for a very long time—enough time for all this descent with modification to occur! This is Hutton and Lyell’s contribution to Darwin’s theory: Deep time gave enough time for natural selection to act. For evidence of descent with modification over long periods of time, Darwin pointed to the fossil record.

Darwin based his explanation for the diversity of life on the idea that species change over time. To illustrate this idea, he drew the very first evolutionary tree, shown in Figure 16–12. This “tree-thinking” implies that all organisms are related. Look back in time, and you will find common ancestors shared by tigers, panthers, and cheetahs. Look farther back, and you will find ancestors that these felines share with dogs, then horses, and then bats. Farther back still is the common ancestor that all mammals share with birds, alligators, and fish. Far enough back are the common ancestors of all living things. According to the principle of common descent, all species—living and extinct—are descended from ancient common ancestors. A single “tree of life” links all living things.
0001_Bio10_se_Ch16_S3.indd   5 6/2/09   7:37:30 PM
0001_Bio10_se_Ch16_S4.indd   1 6/2/09   7:38:05 PM
43x6
0448_mlbio10_Ch16.indd   180448_mlbio10_Ch16.indd   18 6/29/09   1:12:53 PM
6/29/09   1:12:53 PM
[87x173]Darwin’s theory of evolution by natural selection?
[87x158]EVIDENCE OF UNDERSTANDING
[87x184]GUIDING QUESTION
[87x101]line of evidence.
[87x112]theory of evolution by natural selection. Students should include examples of each
[87x124]presentation with visuals outlining the main lines of evidence that support Darwin’s
[87x135]Darwin’s theory of evolution.
[87x135]Ask pairs of students to create and present an oral
[87x147]following assessment to show their understanding of the evidence that supports
[87x199]common ancestors.
[92x343]distantly related species to develop similar adaptations.
[92x353]however, provide evidence that similar selection pressures had caused
[92x372]in body structures among those animals provide evidence that they
[92x391]inhabit similar grasslands in Europe, Australia, and Africa. Differences
[92x529]lived in the past.
[92x538]study of where organisms live now and where they and their ancestors
[92x684]involved many scientific fields. Scientists in some fields, including geol-
[92x481]related species develop similarities in similar environments.
[92x490]different climates. The second is a pattern in which very distantly
[92x500]species tell us how modern organisms evolved from their ancestors.
[92x548]THINK ABOUT IT Darwin’s theory depended on assumptions that
[92x569]their evolutionary history?
[92x636]Species
[92x636], discoveries in all these fields have served as independent tests
[92x645]exist yet! In the 150 years since Darwin published On the Origin of
[92x665]the technology or understanding to test Darwin’s assumptions during
[92x674]ogy, physics, paleontology, chemistry, and embryology, did not have
[92x617]every scientific test has supported Darwin’s basic ideas about evolution.
[92x626]that could have supported or refuted Darwin’s work. Astonishingly,

**Biogeography**

**How does the geographic distribution of species today relate to their evolutionary history?**

Darwin recognized the importance of patterns in the distribution of life—the subject of the field called biogeography. **Biogeography** is the study of where organisms live now and where they and their ancestors lived in the past. Patterns in the distribution of living and fossil species tell us how modern organisms evolved from their ancestors. Two biogeographical patterns are significant to Darwin’s theory. The first is a pattern in which closely related species differentiate in slightly different climates. The second is a pattern in which very distantly related species develop similarities in similar environments.

**Closely Related but Different** To Darwin, the biogeography of Galápagos species suggested that populations on the island had evolved from mainland species. Over time, natural selection on the islands produced variations among populations that resulted in different, but closely related, island species.

**Distantly Related but Similar** On the other hand, similar habitats around the world are often home to animals and plants that are only distantly related. Darwin noted that similar ground-dwelling birds inhabit similar grasslands in Europe, Australia, and Africa. Differences in body structures among those animals provide evidence that they evolved from different ancestors. Similarities among those animals, however, provide evidence that similar selection pressures had caused distantly related species to develop similar adaptations.

**Key Questions**

- **How does the geographic distribution of species today relate to their evolutionary history?**
- **How do fossils help to document the descent of modern species from ancient ancestors?**
- **What do homologous structures and similarities in embryonic development suggest about the process of evolutionary change?**
- **How can molecular biology be used to trace the process of evolution?**
- **What does recent research on the Galápagos finches show about natural selection?**

**Vocabulary**

biogeography
homologous structure
analogous structure
vestigial structure

**Taking Notes**

**Concept Map** Construct a concept map that shows the kinds of evidence that support the theory of evolution.

**Mystery CLUE**

*How can biogeography help explain why some species of honeycreepers are found only on the Hawaiian Islands?*

**Student Resources**

- **Study Workbooks A and B, 16.4 Worksheets**
- **Spanish Study Workbook, 16.4 Worksheets**
- **Lab Manual B, 16.4 Data Analysis Worksheet, Hands-On Activity Worksheet**

**Getting Started**

**Objectives**

16.4.1 Explain how geologic distribution of species relates to their evolutionary history.
16.4.2 Explain how fossils and the fossil record document the descent of modern species from ancient ancestors.
16.4.3 Describe what homologous structures and embryology suggest about the process of evolutionary change.
16.4.4 Explain how molecular evidence can be used to trace the process of evolution.
16.4.5 Explain the results of the Grants’ investigation of adaptation in Galápagos finches.

**UNIFYING CONCEPTS AND PROCESSES**

I, II, III, IV, V

**CONTENT**

C.1.f, C.2.a, C.3.a, C.3.c, C.3.d, D.3, E.2, G.1, G.2, G.3

**INQUIRY**

A.1.c, A.2.a, A.2.b, A.2.c, A.2.d, A.2.e, A.2.f
The limb structure of *Ambulocetus* ("walking whale") suggests that these animals could both swim in shallow water and walk on land.

The hind limbs of *Rodhocetus* were short and probably not able to bear much weight. Paleontologists think that these animals spent most of their time in the water.

**EVIDENCE FROM FOSSILS**

**FIGURE 16–13** Recently, researchers have found more than 20 related fossils that document the evolution of modern whales from ancestors that walked on land. Several reconstructions based on fossil evidence are shown below in addition to the modern mysticete and odontocete. *Infer* Which of the animals shown was probably the most recent to live primarily on land?

**DIFFERENTIATED INSTRUCTION**

**L1 Special Needs** Students may have a better understanding of fossils after doing this simple simulation. Have them place a small seashell at the bottom of a beaker that is about half full of water and then add a couple handfuls of soil to the beaker. Tell them to observe as the soil gradually settles to the bottom and covers the shell. Relate this to how dead organisms sink to the bottom of the ocean and become buried with sediments. Explain that the pressure of the water and additional sediments very slowly turns the dead organisms into fossils.

**Answer**

**FIGURE 16–13** *Ambulocetus*

**Biology In-Depth**

**THE EVOLUTION OF WHALES**

Fossils that provide evidence for the transition from land to water show that the transition took only 10 million years, which is a very short time in evolutionary terms. *Pakicetus* was first discovered in 1979 by paleontologist Philip Gingerich in Pakistan. In 1994, Gingerich’s former student, J. Thewissen found *Ambulocetus*—a whale that lived about 50 million years ago and was probably amphibious. *Rodhocetus*, discovered by Gingerich in the 1990s, lived about 45 million years ago and was the earliest known completely aquatic mammal in the whale lineage. It is the ankle bone anatomy of *Rodhocetus* and another whale ancestor called *Artiocetus*, however, that proved to be the most important. The particular shape of the ancient whales’ ankle bones allowed Gingerich to pinpoint their ancestry to artiodactyls—not to a group of extinct carnivores called mesonychids as previously thought.
Recent Fossil Finds  Darwin also struggled with what he called the “imperfection of the geological record.” Darwin’s study of fossils had convinced him and other scientists that life evolved. But paleontologists in 1859 hadn’t found enough fossils of intermediate forms of life to document the evolution of modern species from their ancestors. Many recently discovered fossils form series that trace the evolution of modern species from extinct ancestors.

Since Darwin, paleontologists have discovered hundreds of fossils that document intermediate stages in the evolution of many different groups of modern species. One recently discovered fossil series documents the evolution of whales from ancient land mammals, as shown in Figure 16–13. Other recent fossil finds connect the dots between dinosaurs and birds, and between fish and four-legged land animals. In fact, so many intermediate forms have been found that it is often hard to tell where one group begins and another ends. All historical records are incomplete, and the history of life is no exception. The evidence we do have, however, tells an unmistakable story of evolutionary change.

Lead a Discussion  Tell students fossils of whale ancestors have been found in places that are no longer covered by water. For example, fossils of Ambulocetus and Rodhocetus were found in desert regions of Pakistan.

Ask  How could fossils for amphibious or aquatic organisms be found in a desert? (The environment changed since the organisms represented by the fossils lived there.)

Use this example to start a general discussion of how environmental change is related to natural selection.

DIFFERENTIATED INSTRUCTION  ELL  English Language Learners  Use a Question-Answer Relationships strategy to help students glean the most important information from the passage, Recent Fossil Finds. Write the following questions on the board, and before students answer them, have them decide whether each question is a Right There, Think and Search, Author and You, or On My Own question:

- What was Darwin convinced of from his study of fossils? (Right There)
- Why did Darwin struggle with the “imperfection of the geological record”? (Think and Search)
- What traits do you think a species would have that was intermediate between dinosaurs and birds? (On My Own)

Study Wkbks A/B, Appendix S10, Question-Answer Relationships.

Address Misconceptions  Gaps in the Fossil Record  Students commonly presume that missing intermediate fossils disprove Darwin’s theory of evolution by natural selection. Stress how rare it is for fossils to form in the first place, let alone to be found by paleontologists! Then, describe some of the many intermediate fossils that have been found since Darwin’s time, such as fossils showing that land animals descended from aquatic animals (Lesson 26.2), that whales descended from land-living ancestors, or that birds descended from nonflying dinosaurs.

How Science Works  MINI DINOSAUR PROVIDES MISSING LINK  For decades, one of the most significant pieces of “missing” data for the evolution of birds from nonflying dinosaurs was evidence for a reduction in body size. Dinosaurs were generally large animals, and a relatively small body is a necessary prerequisite for flight. An 80-million-year-old fossil dinosaur found in China’s Gobi Desert in 2007, named Mahakala omnogovae, provided the missing evidence. This diminutive dinosaur was only 70 centimeters long. It was the first known dinosaur that would have been small enough to fly. It also had winglike limbs, and probably had feathers.
LESSON 16.4 • Art Review

DIFFERENTIATED INSTRUCTION

Less Proficient Readers Homologous and analogous structures are readily confused, but it’s important for students to be able to distinguish between them because of their different evolutionary implications. Guide students in filling in a Compare/Contrast Table for the two types of structures. For column headings, tell them to use Homologous Structure and Analogous Structure. For row headings, have them use: What is it? What does it mean? What is an example? Students can complete the table as they read about the structures in the text.

Study Wkbks A/B, Appendix S20, Compare/Contrast Table. Transparencies, GO3.

Students can review homologous and analogous structures in the drag-and-drop activity, Art Review: Homologous and Analogous.

Quick Facts

VESTIGIAL STRUCTURES AND PROCESSES IN HUMANS

Classical examples of vestigial structures in humans include the appendix, which is an extension of the cecum of the large intestine. It plays an important role in digestion in some mammals but appears—although this is debated—to have little function in humans. Other vestigial structures in humans are the tailbones at the base of the spine. They are miniature remnants of bones that form the tail in many other animals. Try to use the muscles in your head to move your ears like a dog or cat, and the most you’re likely to manage is a slight twitch. That’s because the muscles that control ear movement are also vestigial structures in humans. Physiological processes, as well as structures, may be vestigial. Getting goosebumps when we are cold is an example. When this occurs, body hairs stand on end. This helps retain body heat in animals with thick body hair but has no effect in relatively hairless humans.
For example, despite the very different adult shapes and functions, the early developmental stages of many animals with backbones (called vertebrates) look very similar. Recent observations make clear that the same bodies that produce many homologous tissues and organs in vertebrates also develop in the same order and in similar clumps of embryonic cells. Evolutionary theory offers the most logical explanation for these similarities in patterns of development.

Analogous Structures

Note that the clue to common descent is common structure, not common function. A bird’s wing and a horse’s front limb have different functions but similar structures. Body parts that share common function, but not structure, are called analogous structures. The wing of a bee and the wing of a bird are analogous structures.

In Your Notebook Do you think the shell of a clam and the shell of a lobster are homologous or analogous structures? Explain.

Vestigial Structures

Not all homologous structures have important functions. Vestigial structures are inherited from ancestors but have lost much or all of their original function due to different selection pressures acting on the descendant. For example, the hipbones of the bottlenose dolphin, shown on page 467, are vestigial structures. In their ancestors, hipbones played a role in terrestrial locomotion. However, as the dolphin lineage adapted to life at sea, this function was lost. Why do dolphins and the organisms in Figure 16–15 retain structures with little or no function? One possibility is that the presence of the structure does not affect an organism’s fitness, and, therefore, natural selection does not act to eliminate it.

Embryology

Researchers noticed a long time ago that the early developmental stages of many animals with backbones (called vertebrates) look very similar. Recent observations make clear that the same groups of embryonic cells develop in the same order and in similar patterns to produce many homologous tissues and organs in vertebrates. For example, despite the very different adult shapes and functions of the limb bones in Figure 16–14, all those bones develop from the same clumps of embryonic cells. Evolutionary theory offers the most logical explanation for these similarities in patterns of development.

Similar patterns of embryological development provide further evidence that organisms have descended from a common ancestor.

Darwin realized that similar patterns of development offer important clues to the ancestry of living organisms. He could not have anticipated, however, the incredible amount of evidence for his theory that would come from studying the genes that control development—evidence from the fields of genetics and molecular biology.

Biology In-Depth

EMBRYOLOGICAL SIMILARITIES

For more than a hundred years, biologists have been fascinated by the fact that organisms as dissimilar as chickens, snakes, and dogs show striking similarities in their early development. For example, in reptiles and birds, a sac grows around the large amount of yolk that is stored to support the embryo’s growth. Placental mammals, on the other hand, depend upon the bodies of their mothers for nourishment—therefore, their eggs contain very little yolk. Nonetheless, mammalian embryos still form a large and recognizable yolk sac, although it is completely empty. Why? Evolutionary biology answers that question—because mammals are descended from animals (reptiles) that once required the yolk sac, they still produce the sac even though today it has no yolk to surround.

Lead a Discussion

After students read about vestigial structures, lead a discussion about why vestigial structures persist in organisms.

Ask In terms of natural selection, what must be true about vestigial structures if they remain in a population? (They must not be strongly selected against in the current environment.)

Clarify that the term vestigial is not synonymous with “useless.” Explain that sometimes, a vestigial structure can have a non-obvious function. For example, the vestigial hipbones of large whales seem to play a role in male reproduction.

Ask How does a secondary function, as in the hipbones of some large whales, help to explain why vestigial structures remain? (If the structure has a function, then it’s more likely that it is selected for in terms of natural selection. For example, if the whale needs the vestigial hipbones to reproduce, individuals without the vestigial bones will have a very low fitness.)

DIFFERENTIATED INSTRUCTION

Advanced Students Have interested students explore recent scientific findings involving the human appendix. Though still often referred to as a vestigial organ, the appendix is now thought by some scientists to serve as a “safe house” for good bacteria in the human digestive tract. Have students write a paragraph explaining what they found and how it ties in with the discussion of how some structures take on secondary functions.

Answers

FIGURE 16–15 Sample answer: I think the skink’s ancestors had functioning legs, because the skink’s legs look like vestigial structures. They probably declined in size due to different selection pressures in the descendants.

IN YOUR NOTEBOOK The shell of a clam and the shell of a lobster are probably analogous, because they have a common function (protection, support), but not a common structure.
LEsson 16.4

Teach continued

Lead a Discussion

Ask students which type of evidence for evolution they think is more informative, fossil evidence or genetic evidence. After several students have weighed in on the issue, discuss what can and cannot be learned from each type of evidence. For example, molecular data can indicate how long living organisms have been evolving separately. However, unlike fossils, molecular evidence does not give any indication of what extinct organisms looked like, how they moved, or what they ate.

Differentiated Instruction

Struggling Students Use a Directed Reading-Thinking Activity to help students comprehend the passage, Genetics and Molecular Biology. Have them skim the passage by examining the headings, Key Concept, and Figure 16–16. Ask them to predict what the passage will be about and explain why they think so. Then, when they read, have them pause after each paragraph to evaluate what they just learned.

Study Wkbks A/B, Appendix S5, Directed Reading-Thinking Activity.

Genetics and Molecular Biology

How can molecular biology be used to trace the process of evolution?

The most troublesome “missing information” for Darwin had to do with heredity. Darwin had no idea how heredity worked, and he was deeply worried that this lack of knowledge might prove fatal to his theory. As it happens, some of the strongest evidence supporting evolutionary theory comes from genetics. A long series of discoveries, from Mendel to Watson and Crick to genomics, helps explain how evolution works. At the molecular level, the universal genetic code and homologous molecules provide evidence of common descent. Also, we now understand how mutation and the reshuffling of genes during sexual reproduction produce the heritable variation on which natural selection operates.

Life’s Common Genetic Code One dramatic example of molecular evidence for evolution is so basic that by this point in your study of biology you might take it for granted. All living cells use information coded in DNA and RNA to carry information from one generation to the next and to direct protein synthesis. This genetic code is nearly identical in almost all organisms, including bacteria, yeasts, plants, fungi, and animals. This is powerful evidence that all organisms evolved from common ancestors that shared this code.

470 Chapter 16 • Lesson 4

Molecular Homology in Hoxc8

Molecular homologies can be used to infer relationships among organisms. The diagram below shows a small portion of the DNA for the same gene, Hoxc8, in three animals—a mouse, a baleen whale, and a chicken.

1. Calculate What percentage of the nucleotides in the baleen whale’s DNA are different from those of the mouse? (Hint: First count the number of DNA nucleotides in one entire sequence. Then count the nucleotides in the whale DNA that differ from those in the mouse DNA. Finally, divide the number of nucleotides that are different by the total number of nucleotides, and multiply the result by 100.)

<table>
<thead>
<tr>
<th>Animal</th>
<th>Sequence of Bases in Section of Hoxc8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse</td>
<td>CAGAAAATGCACTTTATGGCCCTGTGTCCTCGCTC</td>
</tr>
<tr>
<td>Balaen whale</td>
<td>CGAAAATGCCTCTTTATGGGCCGTGTCCTCGGC</td>
</tr>
<tr>
<td>Chicken</td>
<td>AAAAAATGCGCTTTAAGCTGTGTCCTCGCTA</td>
</tr>
</tbody>
</table>

2. Calculate What percentage of the nucleotides in the chicken are different from those of the mouse?
3. Draw Conclusions Do you think a mouse is more closely related to a baleen whale or to a chicken? Explain your answer.
4. Evaluate Do you think that scientists can use small sections of DNA, like the ones shown here, to infer evolutionary relationships? Why or why not?

Sample answer: I think a mouse is more closely related to a baleen whale than to a chicken, because it shares a greater percentage of nucleotides with the whale.

Sample answer: Scientists probably prefer not to use small sections of DNA to infer evolutionary relationships, because chance could play too big a role in the results. They probably try to use larger sections of DNA in their analyses.

ANSWERS

1. 10 percent
2. 20 percent

470 Chapter 16 • Lesson 4
Testing Natural Selection

What does recent research on the Galápagos finches show about natural selection?

One way to gather evidence for evolutionary change is to observe natural selection in action. But most kinds of evolutionary change we've discussed so far took place over millions of years—which makes it tough to see change actually happening. Some kinds of evolutionary change, however, have been observed and studied repeatedly in labs and in controlled outdoor environments. Scientists have designed experiments involving organisms from bacteria to guppies to test Darwin's theories. Each time, the results have supported Darwin's basic ideas. But one of the best examples of natural selection in action comes from observations on animals living in their natural environment. Fittingly, those observations focused on Galápagos finches.

A Testable Hypothesis

Remember that when Darwin first saw the Galápagos finches, he thought they were wrens, warblers, and blackbirds because they looked so different from one another. Once Darwin learned that the birds were all finches, he hypothesized that they had descended from a common ancestor.

Connect to the Real-World

Explain to students that one of the most striking examples of a small change in Hox gene expression resulting in a major change to an organism is the snake. Pythons have hundreds of vertebrae. Unlike many reptiles, which show regionalization of their backbone into neck, chest, back, and tail regions, each vertebra (except the atlas) anterior to the hindlimbs in pythons (which appear as tiny vestigial buds in development) resembles a chest vertebra. Research first published in 1999 suggests that broadened expression of two Hox genes accounts for both the loss of front limbs and the incredibly elongated thoracic (chest) region of the python.

DIFFERENTIATED INSTRUCTION

Advanced Students

Challenge students to predict how assumptions about neutral mutation rates and data on homologous molecules in two different species could be used to estimate the time since the two species shared a common ancestor. Tell students to check their prediction by reading about molecular clocks in Lesson 17.

Focus on ELL:

Access Content

ALL SPEAKERS Divide students into four study groups for a Jigsaw Review of the material in this lesson. Assign each group one of the following sources of evolution evidence: the age of the Earth and fossils, comparative anatomy and embryology, genetics and molecular biology, and testing natural selection in nature. Have each study group review their material together. Then, form four new groups, mixing up members from each group who will serve as the “expert” in the learning circles on their topic in the new group. Have these new groups discuss the contents of the lesson and record any remaining questions they have. These questions can be addressed when the class reforms.

Study Wkbks A/B, Appendix S7, Jigsaw Review.
phasenistic changes happen too slowly to be observed directly. The Grants truly took over where Darwin left off. The Grants have spent more than 35 years studying Galápagos finches. They realized that Darwin’s hypothesis rested on two testable assumptions. First, for beak size and shape to evolve, there must be enough heritable variation in those traits to provide raw material for natural selection. Second, differences in beak size and shape must produce differences in fitness. The Grants have tested these hypotheses on the medium ground finch (Geospiza) on the island of Daphne Major. This island is large enough to support good-sized finch populations, yet small enough to allow the Grants to catch, tag, and identify nearly every bird of the species. During their study, the Grants periodically recapture the birds. They record which individuals are alive and which have died, which have reproduced and which have not. For each individual, the Grants record anatomical characteristics like wing length, leg length, beak length, beak depth, beak color, feather colors, and total mass. The data the Grants have recorded show that there is indeed great variation of heritable traits among Galápagos finches.

Natural Selection The Grants’ data have shown that individual finches with different-size beaks have better or worse chances of surviving both seasonal droughts and longer dry spells. When food becomes scarce during dry periods, birds with the largest beaks are more likely to survive, as shown in Figure 16–18. As a result, average beak size in this finch population has increased dramatically. The Grants have documented that natural selection takes place in wild finch populations frequently, and sometimes rapidly. Changes in food supply created selection pressure that caused finch populations to evolve within decades. This evolutionary change occurred much faster than many researchers thought possible.

**How Science Works**

**SIGNIFICANCE OF THE GRANTS’ RESEARCH**

The Galápagos research of Peter and Rosemary Grant is widely acknowledged to be the most important field study of evolutionary processes that has been undertaken in the last three decades. The work has had a major influence on several fields of biology, including ecology, evolution, and population biology. The Grants began their research with finches on the Galápagos Islands in 1973. Since then, they have studied almost 20,000 individual birds over 25 generations. The evidence they have gathered has documented mechanisms of evolutionary change that, until their research, had only been postulated. The Grants truly took over where Darwin left off.
Not only have the Grants documented natural selection in nature, their data also confirm that competition and environmental change drive natural selection. Traits that don’t matter much under one set of environmental conditions become adaptive as the environment changes during a drought. The Grants’ work shows that variation within a species increases the likelihood of the species adapting to and surviving environmental change. Without heritable variation in beak sizes, the medium ground finch would not be able to adapt to feeding on larger, tougher seeds during a drought.

**Assessment Answers**

1a. the study of where organisms live now and where they and their ancestors lived in the past

1b. because they evolved similar adaptations to the same environmental conditions in different places

2a. Fossils provide direct evidence of extinct organisms and allow scientists to trace the evolution of modern species from extinct ancestors.

2b. Sample answer: A modern mysticete whale has a large, streamlined body with fins and a tail but lacks legs. *Ambulocetus* had a smaller, four-legged body with a tail but no fins.

3a. Vestigial structures offer clues about the ancestors of organisms, because they are the remnants of structures with once important functions.

3b. Homologous structures share a common ancestry, but not necessarily a common function. Analogous structures share a common function, but do not share a common ancestry. Generally, homologous structures are more important to evolutionary biologists, because they provide evidence of evolutionary relationships.

4a. Hox genes control the timing of development and growth in embryos.

4b. The similarities indicate that organisms A and B likely share a recent common ancestor.

5a. Natural selection shaped the beaks of different bird populations.

5b. Their data show that variation within a species increases the likelihood of the species adapting to and surviving environmental change.

6. Students’ answers should include mention of biogeography, the age of Earth and fossil finds, homologous structures and embryology, and observations of natural selection.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Amino Acid Sequences: Indicators of Evolution described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 398.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP IV

CONTENT C.2.a, C.2.c, C.3.d, C.3.e

INQUIRY A.1.e

Pre-Lab Answers

BACKGROUND QUESTIONS

a. Homologous molecules have extensive similarities in structure and in chemistry.

b. Sample answer: Because rabbits and fruit flies are distantly related, they don’t have many visible structures that can be used to establish their relatedness.

c. The order of bases in the related segment of DNA must be similar in both organisms because the sequence of bases in a gene controls the sequence of amino acids in the protein.

PRE-LAB QUESTIONS

1. Students are likely to say that chimpanzees and gorillas have a more recent common ancestor with humans than do bears and mice.

2. Students can compare retelling the story to the replication of DNA and the changes in the story to mutations. Despite the differences in time frame, with both the story and the DNA the number of changes will increase with time.

3. The common ancestor should be placed relatively recently along the tree based on the limited differences between the proteins and the time required for mutations to occur.
Study Guide

16.1 Darwin’s Voyage of Discovery

Darwin developed a scientific theory of biological evolution that explains how modern organisms evolved over long periods of time through descent from common ancestors.

Darwin noticed that (1) different, yet ecologically similar, animal species inhabited separated, but ecologically similar, habitats around the globe; (2) different, yet related, animal species often occupied different habitats within a local area; and (3) some fossils of extinct animals were similar to living species.

16.2 Ideas That Shaped Darwin’s Thinking

Hutton and Lyell concluded that Earth is extremely old and that the processes that changed Earth in the past are the same processes that operate in the present.

Lamarck suggested that organisms could change during their lifetimes by selectively using or not using various parts of their bodies. He also suggested that individuals could pass these acquired traits on to their offspring, enabling species to change over time.

Malthus reasoned that if the human population grew unchecked, there wouldn’t be enough living space and food for everyone.

In artificial selection, nature provides the variations, and humans select those they find useful.

16.3 Darwin Presents His Case

Natural selection occurs in any situation in which more individuals are born than can survive, there is natural heritable variation, and there is variable fitness among individuals.

According to the principle of common descent, all species—living and extinct—are descended from ancient common ancestors.

16.4 Evidence of Evolution

Patterns in the distribution of living and fossil species tell us how modern organisms evolved from their ancestors.

Many recently discovered fossils form series that trace the evolution of modern species from extinct ancestors.

Evolutionary theory explains the existence of homologous structures adapted to different purposes as the result of descent with modification from a common ancestor.

The universal genetic code and homologous molecules provide evidence of common descent.

The Grants have documented that natural selection takes place in wild Galápagos finch populations frequently, and sometimes rapidly, and that variation within a species increases the likelihood of the species adapting to and surviving environmental change.

Think Visually

Using the information in this chapter, create a concept map that links the following terms: adaptation, artificial selection, biogeography, camouflage, Charles Darwin, Charles Lyell, evolution, fitness, fossil, homology, James Hutton, Jean-Baptiste Lamarck, mimicry, natural selection, and Thomas Malthus.

Performance Tasks

SUMMATIVE TASK  Divide the class into small groups, and instruct each group to brainstorm ways Earth might change over the next one million years. Then, have each group select a species living today and predict how populations descended from that species might evolve to adapt to the changes. Groups should describe and sketch specific adaptations in the species they select.

TRANSFER TASK  Tell students to assume that a newspaper has published an article questioning whether evolution occurs. Ask them to write a letter to the editor of the newspaper in which they argue that evolution does occur, using evidence from the chapter to support their argument.

Answers

THINK VISUALLY

Students’ concept maps may vary but should show the following relationships: Hutton, Lamarck, and Malthus influenced the development of Darwin’s theory of evolution by natural selection; natural selection occurs when organisms in a population differ in fitness, and it leads to adaptations such as camouflage and mimicry; evidence for evolution includes fossils, artificial selection, homologies, and biogeography.
Lesson 16.1

UNDERSTAND KEY CONCEPTS

1. c  2. a
3. Darwin observed that each of these distantly related large, flightless birds found in a different but ecologically similar habitat around the globe shared many similarities in form and function.
4. Closely related Galápagos tortoises exhibited different traits depending on the environment of the island where they lived.

THINK CRITICALLY

5. Sample answer: Evolution means change over time. An example of evolution is the change over time in some bacteria that allows them to resist drugs.
6. Darwin’s trip allowed him to observe, in a variety of habitats, patterns of biodiversity that result from evolution by natural selection.
7. Because some Australian habitats seemed to be ideal for rabbits, and similar grasslands in Europe had rabbits

Lesson 16.2

UNDERSTAND KEY CONCEPTS

8. a  9. d
10. Geological processes uplifted a former sea bed to form mountains.
11. Lyell proposed that Earth is extremely old and processes that changed Earth in the past are still at work today. This allowed for the great time span Darwin believed was necessary for evolution to occur. It also provided a geological analogy for biological evolution.
12. According to Malthus, population growth is limited by overcrowding and lack of food, which in turn lead to war, famine, and disease. His ideas apply to other organisms better than to humans, because other organisms can produce many more offspring over their lifetimes than humans.
13. Artificial selection is the process of selectively breeding plants and animals to have the traits desired by breeders or farmers. Artificial selection showed Darwin how heritable traits of organisms could change over time.

THINK CRITICALLY

14. Like many other organisms, sunflowers produce far more seeds than can survive and grow into mature plants. Most of the seeds will not germinate or the plants they develop into will die before they reach maturity.
15. Lamarck was one of the first naturalists to suggest that species are not fixed, and he tried to explain evolution scientifically using natural processes. He also recognized that there is a link between an organism’s environment and its body structures.
16. b  17. a
18. Variation is necessary if some organisms are to have greater fitness than others and to have a greater chance of passing on their traits to the next generation.
19. The statement means that living species are descended, with modification, from common ancestors. This implies that all organisms are related if you go back far enough in time. In other words, a single “tree of life” links all living things.
20. For natural selection to occur, there must be overproduction of offspring and variation among the heritable traits in organisms, and these variations must correlate to differences in fitness.
16.3 Islands are often home to species that exist nowhere else on Earth. They are species of small birds found nowhere else on Earth. They live on islands that are separated from one another by stretches of open sea and that are hundreds of miles from the nearest continent. They are also related to finches.

There are more than 20 known species of Hawaiian honeycreeper. Like the species of Galápagos finches, the honeycreeper species are closely related to one another. This is an indication that they are all descended, with modifications, from a relatively recent common ancestor. Experts think the ancestor colonized the islands between 3 million and 4 million years ago. Many honeycreepers have specialized diets, evolutionary adaptations to life on the particular islands they call home. Today, habitat loss is endangering most of the honeycreepers. In fact, many species of honeycreeper are thought to have become extinct since humans settled on the islands.

1. **Infer** Suppose a small group of birds, not unlike the modern honeycreepers, landed on one of Hawaii’s islands millions of years ago and then reproduced. Do you think all the descendants would have stayed on that one island? Explain your answer.

2. **Infer** Do you think the climate and other environmental conditions are exactly the same everywhere on the Hawaiian Islands? How might environmental conditions have affected the evolution of honeycreeper species?

3. **Form a Hypothesis** Explain how the different species of honeycreepers in Hawaii today might have evolved from one ancestral species.

4. **Connect to the Big idea** Why are islands often home to species that exist nowhere else on Earth?

**THINK CRITICALLY**

21. Darwin would explain the long legs of the water bird as an adaptation that evolved through natural selection. Lamarck would explain the long legs of the bird as an adaptation that evolved through the inheritance of acquired characteristics.

22. Fitness refers to how well an individual can survive and reproduce in its environment relative to other individuals of the same species. Adaptation refers to any heritable characteristic that increases an organism’s fitness.

23. The Galápagos Islands varied in their environments, so organisms with different traits were better suited for different islands. Over time, natural selection for different traits on each island led to variation in the species.

24. **Sample answer:** Nest-building behavior might be an adaptation that ensures reproductive fitness, because it would help protect eggs and newly hatched birds. As a result, the offspring of nest-building birds would be more likely to survive.
Lesson 16.4

UNDERSTAND KEY CONCEPTS
25. c 26. a

27. Sample answer: Patterns in the distribution of living and fossil species show how modern organisms evolved from their ancestors.

28. because these features are remnants of structures that functioned in the organism’s ancestors.

29. The universal genetic code in DNA and RNA shows that all living species descended from an ancient common ancestor.

THINK CRITICALLY
30. A cat, because cats and dogs shared a common ancestor more recently than did crickets and dogs.

31. The fact that the same molecule carries oxygen in the blood of all vertebrates indicates that all vertebrates have a common ancestor.

32. Sample answer: I think that some species of snake might have vestigial hip and leg bones, because snakes are reptiles and other reptiles have hips and legs inherited from an ancient vertebrate ancestor.

WRITE ABOUT SCIENCE
35. Sample answer: Most examples of evolution must have occurred over a very long time period to bring about the great diversity of living and fossil species. Therefore, an ancient age for Earth supports the theory of evolution.

36. Natural selection occurs when there are more organisms born than can survive and variation among the heritable traits of organisms that results in some organisms having greater fitness than others. Check that students identify three lines of evidence that support evolution.

37. Answers will vary. Students should correctly explain Darwin’s theory of evolution by natural selection.

38. Sample answer: If there was a drought, the grass might turn yellow. As a result, the number of green grasshoppers would decline, while the number of yellow grasshoppers would increase.

33. Infer: Based on what you can see, which mouse—white or brown—are better adapted to their environment? Explain your answer.

34. Apply Concepts: In what way is the coloring of the brown mice an adaptation? What other adaptations besides coloring might affect the mouse’s ability to survive and reproduce?

WRITE ABOUT SCIENCE
35. Explain: Write a paragraph that explains how the age of Earth supports the theory of evolution.

36. Summary: Summarize the conditions under which natural selection occurs. Then, describe three lines of evidence that support the theory of evolution by natural selection.

37. Assess the: Write a newspaper article about the meeting at which Darwin’s and Wallace’s hypotheses of evolution were first presented. Explain the theory of evolution by natural selection for an audience that knows nothing about the subject.

38. Assess the: Look back at Figure 16–10 on page 462. Explain how conditions could change so that yellow coloring becomes adaptive. What would happen to the relative numbers of green and yellow grasshoppers in the population?

Connecting Concepts

USE SCIENCE GRAPHICS
33. Sample answer: Brown mice, because they blend in better with their background.

34. Sample answer: The coloring of the brown mouse is an adaptation, because it increases the fitness of the mice in their environment. Other adaptations might include the ability to run fast.

WRITE ABOUT SCIENCE
35. Sample answer: Most examples of evolution must have occurred over a very long time period to bring about the great diversity of living and fossil species. Therefore, an ancient age for Earth supports the theory of evolution.

36. Natural selection occurs when there are more organisms born than can survive and variation among the heritable traits of organisms that results in some organisms having greater fitness than others. Check that students identify three lines of evidence that support evolution.

37. Answers will vary. Students should correctly explain Darwin’s theory of evolution by natural selection.

38. Sample answer: If there was a drought, the grass might turn yellow. As a result, the number of green grasshoppers would decline, while the number of yellow grasshoppers would increase.

39. Interpret Data: Which of these organisms probably shares the most recent common ancestor with chimpanzees?
   a. dog        c. penguin
   b. moth       d. yeast

40. Calculate: The primary structure of cytochrome c contains 104 amino acids. Approximately how many of these amino acids are the same in the chimpanzee and moth?
   a. 10        c. 80
   b. 24        d. 128

ANSWERS
39. a 40. c
Multiple Choice
1. Which scientist formulated the theory of evolution through natural selection?
   A Charles Darwin   C James Hutton
   B Thomas Malthus   D Jean-Baptiste Lamarck
2. Lamarck’s ideas about evolution were wrong because he proposed that
   A species change over time.
   B species descended from other species.
   C acquired characteristics can be inherited.
   D species are adapted to their environments.
3. Lyell’s Principles of Geology influenced Darwin because it explained how
   A organisms change over time.
   B adaptations occur.
   C the surface of Earth changes over time.
   D the Galápagos Islands formed.
4. A farmer’s use of the best livestock for breeding is an example of
   A natural selection.   C extinction.
   B artificial selection.   D adaptation.
5. The ability of an individual organism to survive and reproduce in its natural environment is called
   A natural selection.
   B evolution.
   C descent with modification.
   D fitness.
6. Which of the following is an important concept in Darwin’s theory of evolution by natural selection?
   A descent with modification
   B homologous molecules
   C processes that change the surface of Earth
   D the tendency toward perfection
7. Which of the following does NOT provide evidence for evolution?
   A fossil record
   B natural variation within a species
   C geographical distribution of living things
   D homologous structures of living organisms
8. DNA and RNA provide evidence of evolution because
   A all organisms have nearly identical DNA and RNA.
   B no two organisms have exactly the same DNA.
   C each RNA codon specifies just one amino acid.
   D in most organisms, the same codons specify the same amino acids.
9. A bird’s wings are homologous to a(n)
   A fish’s tailfin.
   B alligator’s claws.
   C dog’s front legs.
   D mosquito’s wings.

Questions 10 and 11
The birds shown below are 2 of the species of finches Darwin found on the Galápagos Islands.

Woodpecker Finch    Large Ground Finch

10. What process produced the two different types of beaks shown?
    A artificial selection
    B natural selection
    C geographical distribution
    D disuse of the beak
11. The large ground finch obtains food by cracking seeds. Its short, strong beak is an example of
    A the struggle for existence.
    B the tendency toward perfection.
    C an adaptation.
    D a vestigial organ.

Open-Ended Response
12. Compare and contrast the processes of artificial selection and natural selection.

Test-Taking Tip
READ ALL THE ANSWER CHOICES
Tell students that it is a good idea to read all the answer choices for multiple choice questions before choosing the correct answer. Explain that wrong choices are often intentionally written to seem as though they could be correct. Therefore, without reading all of the choices, it is easy to make a mistake by selecting the first choice that appears to be correct.