Section 1–2

1 FOCUS

Objectives

1.2.1 ***Describe*** how scientists test hypotheses.

1.2.2 ***Explain*** how a scientific theory develops.

Guide for Reading

Vocabulary Preview

Have students preview the section's Vocabulary terms by skimming the text, finding the highlighted, boldface terms, and writing down the definitions of each in their notebooks.

Reading Strategy

Have students make an outline of the section, using the blue heads as the first level of the outline and the green heads as the second level. Explain that the third and possibly fourth levels of the outline should be supporting details of the topics suggested by the heads.

2 INSTRUCT

Designing an Experiment

Build Science Skills

Applying Concepts Drawing from the green headings in the students' text, write the steps for designing an experiment on the board:

1. Ask a question
2. Form a hypothesis
3. Set up a controlled experiment
4. Record and analyze results
5. Draw a conclusion

Then, have students recall a common superstition, such as the one that proposes that a black cat crossing your path brings bad luck. Ask students how they would use an experiment to verify or disprove this superstition, using the steps written on the board. L2

1–2 How Scientists Work

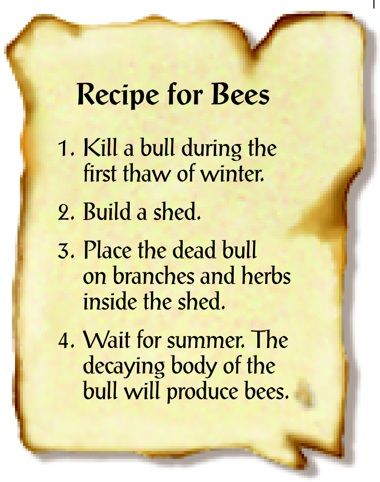
Guide for Reading

Key Concepts
- How do scientists test hypotheses?
- How does a scientific theory develop?

Vocabulary
spontaneous generation
controlled experiment
manipulated variable
responding variable
theory

Reading Strategy: Outlining As you read, make an outline of the main steps in a controlled experiment.

▼ **Figure 1–7** About 2000 years ago, a Roman poet wrote these directions for producing bees. **Inferring** ***Why do you think reasonable individuals once accepted the ideas behind this recipe?***



Have you ever noticed what happens to food that is left in an open trash can for a few days in summer? Creatures that look like worms appear on the discarded food. These creatures are called maggots. For thousands of years people have been observing maggots on food that is not protected. The maggots seem to suddenly appear out of nowhere. Where do they come from?

Designing an Experiment

People's ideas about where some living things come from have changed over the centuries. Exploring this change can help show how science works. Remember that what might seem obvious today was not so obvious thousands of years ago.

About 2300 years ago, the Greek philosopher Aristotle made extensive observations of the natural world. He tried to explain his observations through reasoning. During and after his lifetime, people thought that living things followed a set of natural rules that were different from those for nonliving things. They also thought that special "vital" forces brought some living things into being from nonliving material. These ideas, exemplified by the directions in **Figure 1–7,** persisted for many centuries. About 400 years ago, some people began to challenge these established ideas. They also began to use experiments to answer their questions about life.

Asking a Question For many years, 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. People wondered how these events happened. They were, in their own everyday way, identifying a problem to be solved by asking a question: How do new living things, or organisms, come into being?

Forming a Hypothesis For centuries, people accepted the prevailing explanation for the sudden appearance of some organisms, that some life somehow "arose" from nonliving matter. The maggots arose from the meat, the mice from the grain, and the beetles from the dung. Scholars of the day even gave a name to the idea that life could arise from nonliving matter—**spontaneous generation.** In today's terms, the idea of spontaneous generation can be considered a hypothesis.

In 1668, Francesco Redi, an Italian physician, proposed a different hypothesis for the appearance of maggots. Redi had observed that these organisms appeared on meat a few days after flies were present. He considered it likely that the flies laid eggs too small for people to see. Thus, Redi was proposing a new hypothesis—flies produce maggots. Redi's next step was to test his hypothesis.

TIME SAVER

SECTION RESOURCES

Print:
- ***Teaching Resources,*** Section Review 1–2, Enrichment
- ***Reading and Study Workbook A,*** Section 1–2
- ***Adapted Reading and Study Workbook B,*** Section 1–2
- ***Issues and Decision Making,*** Issues and Decisions 2
- ***Lesson Plans,*** Section 1–2

Technology:
- ***iText,*** Section 1–2
- ***Transparencies Plus,*** Section 1–2

Setting Up a Controlled Experiment In science, testing a hypothesis often involves designing an experiment. The factors in an experiment that can change are called variables. Examples of variables include equipment used, type of material, amount of material, temperature, light, and time.

Suppose you want to know whether an increase in water, light, or fertilizer can speed up plant growth. If you change all three variables at once, you will not be able to tell which variable is responsible for the observed results. **Whenever possible, a hypothesis should be tested by an experiment in which only one variable is changed at a time. All other variables should be kept unchanged, or controlled.** This type of experiment is called a **controlled experiment.** The variable that is deliberately changed is called the **manipulated variable.** The variable that is observed and that changes in response to the manipulated variable is called the **responding variable.**

Based on his hypothesis, Redi made a prediction that keeping flies away from meat would prevent the appearance of maggots. To test this hypothesis, he planned the experiment shown in **Figure 1–8.** Notice that Redi controlled all variables except one—whether or not there was gauze over each jar. The gauze was important because it kept flies off the meat.

CHECKPOINT *What was the responding variable in Redi's experiment?*

Go Online
active art
For: Redi's Experiment activity
Visit: PHSchool.com
Web Code: cbp-1012

▼ **Figure 1–8** **In a controlled experiment, only one variable is tested at a time.** Redi designed an experiment to determine what caused the sudden appearance of maggots. In his experiment, the manipulated variable was the presence or absence of the gauze covering. The results of this experiment helped disprove the hypothesis of spontaneous generation.

Redi's Experiment on Spontaneous Generation

OBSERVATIONS: Flies land on meat that is left uncovered. Later, maggots appear on the meat.

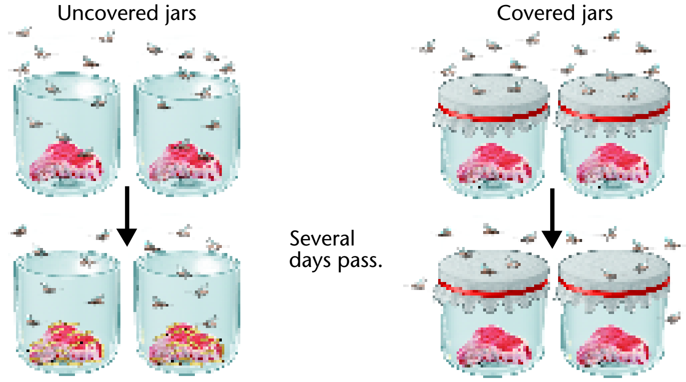
HYPOTHESIS: Flies produce maggots.

PROCEDURE

Controlled Variables: jars, type of meat, location, temperature, time

Manipulated Variable: gauze covering that keeps flies away from meat

Responding Variable: whether maggots appear



CONCLUSION: Maggots form only when flies come in contact with meat. Spontaneous generation of maggots did not occur.

Differentiated Instruction — Solutions for All Learners

Less Proficient Readers
For students who have trouble understanding the three experiments discussed in the section, spend time orally comparing and contrasting the illustrations in Figures 1–8, 1–10, and 1–11. Make sure students can identify the controlled, manipulated, and responding variables in each experiment. L1

English Language Learners
Explain to students that the word *generation* in the term *spontaneous generation* is related to the verb *to generate*, or "to bring into existence." Then, discuss what it means to be "spontaneous" and how the common meaning of the word is related to the meaning used in science. L1 L2

Advanced Learners
Encourage students who need a challenge to investigate how college science textbooks present a systematic approach to problem solving, often called the scientific method. Details will vary, though the basic principles will be the same in all sources. Have these students make a presentation to the class. L3

Go Online
active art
For: Redi's Experiment activity
Visit: PHSchool.com
Web Code: cbe-1012
Students can interact online with the art of Redi's experiment.

Use Visuals

Figure 1–8 Ask students: **What was Redi's hypothesis?** *(Flies produce maggots.)* **Why did he design an experiment that tested only one variable?** *(He designed such an experiment to make sure that any differences he observed during the experiment were caused by that single variable.)* **What was the manipulated variable in Redi's experiment?** *(Whether or not there was gauze over each jar)* **What is the difference that you can see between the two setups?** *(After several days, maggots appear on the meat in the uncovered jars, but no maggots appear on the meat in the covered jars.)* L2

Build Science Skills

Designing Experiments Show students an example or photo of moldy bread. Explain that mold will grow on bread that is exposed to air at room temperature. Then, ask each student to design an experiment to test the effects of water and sunlight on the growth of bread mold. Tell students that they may use up to four slices of bread and any materials available in the classroom. Ask that they ask a question, formulate a hypothesis, and identify the manipulated variable and the control in the proposed experiment. Discuss various experimental designs as a class. Students should take any safety precautions necessary to prevent exposure to mold or mold spores. L2 L3

Answers to . . .

CHECKPOINT *The responding variable was whether maggots appeared.*

Figure 1–7 *A typical response might suggest that without controlled experiments such a recipe could seem logical based on prior observations.*

1–2 (continued)

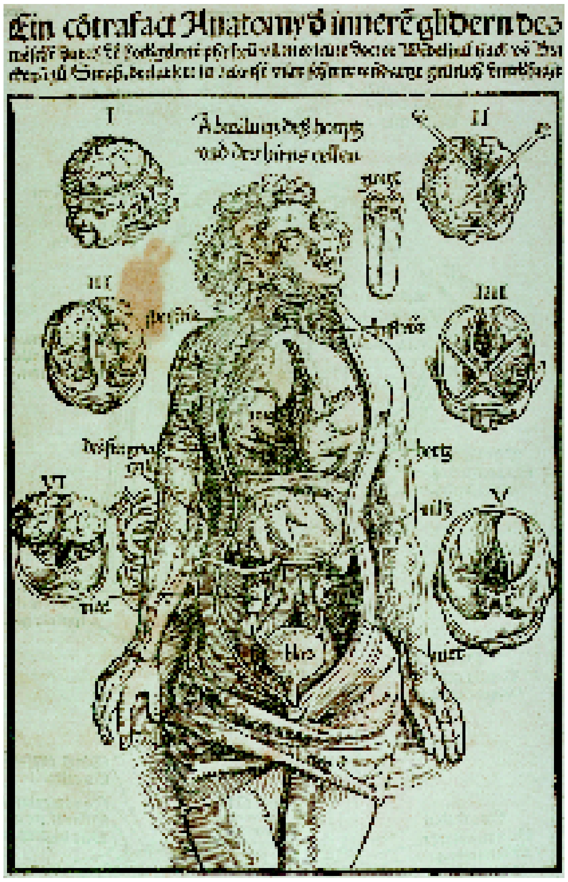
Build Science Skills

Designing Experiments Divide the class into small groups, and have each group consider this question: Does the amount of sleep a student gets affect how well the student does in school? Ask each group to design an experiment that would address that question. Point out that they should ask a question, form a hypothesis, describe a controlled experiment, and describe how the results could be recorded and analyzed. L2

Repeating Investigations

Demonstration

Display a number of periodicals and science journals for students to study, including issues of *Science* and *Nature.* Go over two or three of the experiments described, pointing out the hypothesis, the manipulated variable, the responding variable, the control, the results, and the conclusion for each experiment. Then, divide the class into small groups and assign each group an experiment in one of the journals to analyze according to the experimental process described in their textbook. L2 L3



▲ **Figure 1–9** For centuries, the workings of the human body remained a mystery. Gradually, scientists observed the body's structures and recorded their work in drawings like this. This diagram dates back to fifteenth-century Austria. **Comparing and Contrasting** *How does this drawing compare with the modern illustrations in Unit 10?*

Recording and Analyzing Results

Scientists usually keep written records of their observations, or data. In the past, data were usually recorded by hand, often in notebooks or personal journals. Sometimes, drawings such as **Figure 1–9** recorded certain kinds of observations more completely and accurately than a verbal description could. Today, researchers may record their work on computers. Online storage often makes it easier for researchers to review the data at any time and, if necessary, offer a new explanation for the data. Scientists know that Redi recorded his data because copies of his work were available to later generations of scientists. His investigation showed that maggots appeared on the meat in the control jars. No maggots appeared in the jars covered with gauze.

Drawing a Conclusion Scientists use the data from an experiment to evaluate the hypothesis and draw a valid conclusion. That is, they use the evidence to determine whether the hypothesis was supported or refuted. Redi's results supported his hypothesis. He therefore concluded that the maggots were indeed produced by flies.

As scientists look for explanations for specific observations, they assume that the patterns in nature are consistent. Thus, Redi's results could be viewed not only as an explanation about maggots and flies but also as a refutation of the hypothesis of spontaneous generation.

CHECKPOINT *What did Redi conclude?*

Repeating Investigations

A key assumption in science is that experimental results can be reproduced because nature behaves in a consistent manner. When one particular variable is manipulated in a given set of variables, the result should always be the same. In keeping with this assumption, scientists expect to test one another's investigations. Thus, communicating a description of an experiment is an essential part of science. Today's researchers often publish a report of their work in a scientific journal. Other scientists review the experimental procedures to make sure that the design was without flaws. They often repeat experiments to be sure that the results match those already obtained. In Redi's day, scientific journals were not common, but he communicated his conclusion in a book that included a description of his investigation and its results.

BIO INSIGHTS — HISTORY OF SCIENCE

An emphasis on experimentation
Galileo Galilei (1564–1642) is generally considered to have established the modern scientific method, as demonstrated in his investigations. Some stories about Galileo cannot be verified, including the one about the Leaning Tower of Pisa, but his approach to the study of nature is beyond question. He challenged Aristotle's view that the natural state of a body was at rest, a view accepted for 2000 years. Galileo's discovery of Jupiter's moons supported the Copernican model of the solar system. 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.

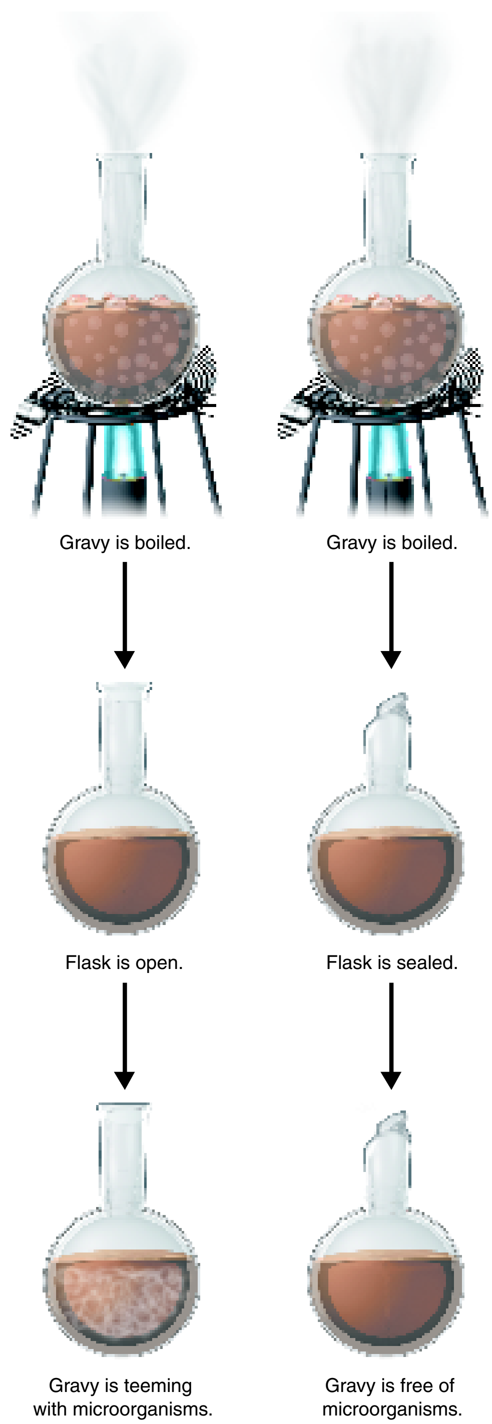
Needham's Test of Redi's Findings Some later tests of Redi's work were influenced by an unexpected discovery. About the time Redi was carrying out his experiment, Anton van Leeuwenhoek (LAY-vun-hook) of the Netherlands discovered a world of tiny moving objects in rainwater, pond water, and dust. Inferring that these objects were alive, he called them "animalcules," or tiny animals. He made drawings of his observations and shared them with other scientists. For the next 200 years or so, scientists could not agree on whether the animalcules were alive or how they came to exist.

In the mid-1700s, John Needham, an English scientist, used an experiment involving animalcules to attack Redi's work. Needham claimed that spontaneous generation could occur under the right conditions. To prove his claim, he sealed a bottle of gravy and heated it. He claimed that the heat had killed any living things that might be in the gravy. After several days, he examined the contents of the bottle and found it swarming with activity. "These little animals," he inferred, "can only have come from juice of the gravy."

Spallanzani's Test of Redi's Findings
An Italian scholar, Lazzaro Spallanzani, read about Redi's and Needham's work. Spallanzani thought that Needham had not heated his samples enough and decided to improve upon Needham's experiment. **Figure 1–10** shows that Spallanzani boiled two containers of gravy, assuming that the boiling would kill any tiny living things, or microorganisms, that were present. He sealed one jar immediately and left the other jar open. After a few days, the gravy in the open jar was teeming with microorganisms. The sealed jar remained free of microorganisms.

Spallanzani concluded that nonliving gravy did not produce living things. The microorganisms in the unsealed jar were offspring of microorganisms that had entered the jar through the air. This experiment and Redi's work supported the hypothesis that new organisms are produced only by existing organisms.

CHECKPOINT *How did Spallanzani's investigative procedures improve upon Needham's work?*



▶ **Figure 1–10** Spallanzani's experiment showed that microorganisms will not grow in boiled gravy that has been sealed but will grow in boiled gravy that is left open to the air. **Interpreting Graphics** *What variable was controlled in this experiment?*

Build Science Skills

Applying Concepts After students have read about Needham's test of Redi's findings, ask: **What was Needham's hypothesis in his experiment?** *(Spontaneous generation could occur under the right conditions.)* **In what way did he change Redi's experiment?** *(Needham heated a sealed bottle of gravy. Redi never used heat in his experiment.)* **What assumption did Needham make that made his results invalid?** *(He assumed that heating the gravy killed all the "animalcules." That assumption was wrong.)* **What is the result when a scientist draws a conclusion from data that are derived from an invalid assumption?** *(The conclusion is flawed.)* L2

Use Visuals

Figure 1–10 Ask students: **What was Spallanzani's hypothesis?** *(Boiling would kill any tiny living things in gravy, and no growth of organisms would occur in a sealed flask.)* **Is boiling the manipulated variable in Spallanzani's experiment? If not, what is?** *(Boiling was not the manipulated variable; the manipulated variable was whether or not the flask was sealed.)* **What variables were kept the same, or controlled, in his experiment?** *(Same gravy, same boiling, same flasks, same time)* L2

BIO INSIGHTS — HISTORY OF SCIENCE

Water teeming with "animalcules"
Anton van Leeuwenhoek had a passion for tiny things. During a lifetime of investigation, he studied the structure of muscle, skin, hair, tooth scrapings, and various small insects. His famous discovery of "animalcules" occurred late in the summer of 1674 when he returned home from boating on a local lake with a sample of the water. That water was cloudy, and most people at the time thought that such cloudiness was caused by a heavy dew. But, when Leeuwenhoek used one of the lenses he had mounted as a microscope, he was surprised to see that the water was teeming with tiny organisms, so many that it was cloudy with them. This and other discoveries made him world-famous. Perhaps his most remarkable discovery was made in 1676 when he described tiny organisms that are now known to have been bacteria.

Answers to . . .

CHECKPOINT *Redi concluded that maggots were produced by flies.*

CHECKPOINT *Spallanzani boiled the gravy, assuming that boiling would kill any microorganisms.*

Figure 1–9 *Students' answers will vary. A typical comparison might suggest that modern illustrations are much more realistic and accurate.*

Figure 1–10 *The main controlled variable was the boiling of the gravy.*

1–2 (continued)

Use Visuals

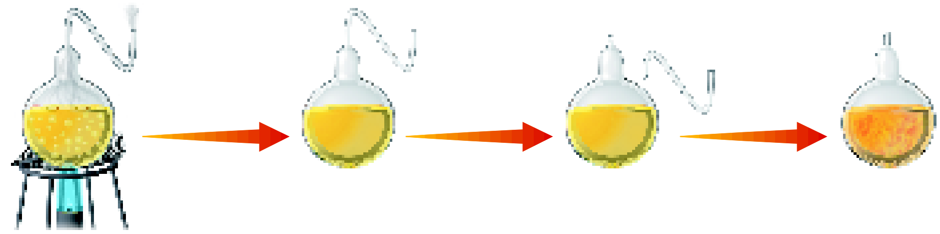
Figure 1–11 Ask students: **What was the hypothesis Pasteur tested in his experiment?** *(As long as broth is protected from microorganisms, it will remain free of living things.)* **Why did Pasteur boil the broth at the beginning of this experiment?** *(To kill any microorganisms in the broth)* **What was the purpose of the curved neck in Pasteur's setup?** *(The curved neck allowed air into the flask but not microorganisms.)* L1 L2

Biology and History

After students have read about the discoveries, add any general events to the time line that students can recall from other classes, such as the Declaration of Independence in 1776, the beginning of the U.S. Civil War in 1861, and the assassination of President Kennedy in 1963. Discuss how each of the discoveries included in the time line changed both science and society. Ask students if there are any other major scientific discoveries they would add to the time line.

Writing in Science

Make sure some students are writing reports about one of the discoveries included on the time line. Explain that for each of the scientists listed, students could probably find a biography in the library. Advise them to look for specialized books in the library's reference section that focus on scientific biography. L2 L3



▲ **Figure 1–11** Pasteur's experiment showed that boiled broth would remain free of microorganisms even if air was allowed in, as long as dust and other particles were kept out. **Inferring** ***Why did microorganisms grow after Pasteur broke the neck of the flask?***

Pasteur's Test of Spontaneous Generation Well into the 1800s, some scientists continued to support the spontaneous generation hypothesis. Some of them argued that air was a necessary factor in the process of generating life because air contained the "life force" needed to produce new life. They pointed out that Spallanzani's experiment was not a fair test because air had been excluded from the sealed jar.

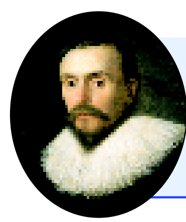
In 1864, an ingenious French scientist, Louis Pasteur, found a way to settle the argument. He designed a flask that had a long curved neck, as shown in **Figure 1–11.** The flask remained

Biology and History

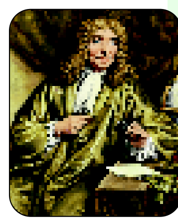
Major Discoveries

The history of biology includes discoveries about the structure of the human body, the nature of cells, how species evolve, ways to fight deadly diseases, and what molecule determines hereditary traits. You will learn about these discoveries as you study this textbook.

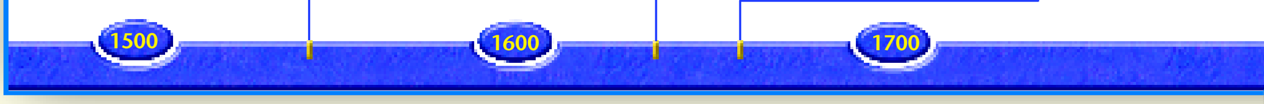
1543
Andreas Vesalius
Vesalius publishes *On the Structure of the Human Body,* the first accurate and detailed study of human anatomy.



1628
William Harvey
Harvey is the first scholar to describe the circulation of blood. He shows how blood pumped through blood vessels returns to the heart and is recirculated.



1673
Anton van Leeuwenhoek
Van Leeuwenhoek perfects the simple microscope and observes cells and microorganisms.



BIO INSIGHTS — HISTORY OF SCIENCE

The dawn of modern science
Andreas Vesalius (1514–1564) was a physician from Brussels, Belgium. Because dissection of human cadavers was forbidden in northern Europe, Vesalius moved to Italy in the 1530s, where he taught anatomy at universities and performed numerous dissections. One of his achievements was to demonstrate that men and women had the same number of ribs—the common belief had been that men had one fewer rib than women, because Eve was created from Adam's rib. In 1543, Vesalius published his book on human anatomy. It contained outstanding illustrations, many of which were done by a student of the great Italian painter Titian. In this groundbreaking work, Vesalius showed the human body in natural positions. It ended the influence of the Greek physician Galen, whose works on anatomy had dominated scientific thinking since the second century.

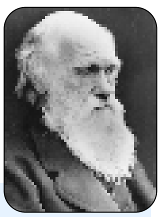
open to the air, but microorganisms from the air did not make their way through the neck into the flask. Pasteur showed that as long as the broth was protected from microorganisms, it remained free of living things. About a year after the experiment began, Pasteur broke the neck of the flask, and the broth quickly became filled with microorganisms. His work convinced other scientists that the hypothesis of spontaneous generation was not correct. In other words, Pasteur showed that all living things come from other living things. This change in thinking represented a major shift in the way scientists viewed living things.

CHECKPOINT *What improvement did Pasteur make to Redi's experiment?*

The Impact of Pasteur's Work During his lifetime, Pasteur made many discoveries related to microorganisms. His research had an impact on society as well as on scientific thought. He saved the French wine industry, which was troubled by unexplained souring of wine, and the silk industry, which was endangered by a silkworm disease. Moreover, he began to uncover the very nature of infectious diseases, showing that they were the result of microorganisms entering the bodies of the victims. Pasteur is considered one of biology's most remarkable problem solvers.

Writing in Science

Find out more about one of these discoveries. Research the person or people who made the discovery and how they did it. Write a one-page report describing the contribution of the scientists.



1859
Charles Darwin
Darwin publishes *On the Origin of Species,* stating that all forms of life have evolved into their present state over the course of millions of years.

1881
Louis Pasteur
Pasteur develops the first vaccine against anthrax, a deadly bacterial disease.

1953
James Watson and Francis Crick
Watson and Crick determine the structure of DNA.

1800 1900 2000

Address Misconceptions

After reading about the experiments of Redi, Spallanzani, and Pasteur, some students may be confused about the steps a scientist takes in carrying out an experiment. To review these steps, use the following activity. Write the steps on a set of index cards. Place the cards face down on a desk or table. Have each student pick a card at random. Ask the students to line themselves up so that the steps they have drawn are in the correct order. Then, have students take turns describing each step. L1

Build Science Skills

Applying Concepts Point out that a jar of pasta sauce is kept on a grocery store shelf or in a cupboard at home unrefrigerated. But, once the top is opened, the jar must be kept in a refrigerator to keep the contents from spoiling. Ask students: **What can you infer from Pasteur's work about why an opened jar must be kept in a refrigerator?** *(Pasteur showed that all living things come from other living things, and opening the jar exposes the contents to organisms in the air, just as breaking the neck of the flask did in his experiment.)* Have students write a description of a controlled experiment they might carry out that would test the hypothesis that organisms would grow in an opened jar of food. L2 L3

TEACHER TO TEACHER

Before introducing Pasteur's test of spontaneous generation, I have students carry out a simulation of his experiment. Students fill three precleaned test tubes with 5–10 mL of nutrient broth. Tube A is left open. Tube B is loosely fitted with an autoclaved rubber stopper, which is always handled with an alcohol-cleaned forceps. Tube C is fitted with a rubber stopper pierced with a bent piece of glass tubing that has also been autoclaved. The three tubes are heated in a boiling-water bath for at least 30–40 minutes and then observed daily for about one week. Students look for signs of turbidity. Tube A will show growth within a day or two. Tubes B and C will stay sterile.

—*Gregory W. McCurdy*
Biology Teacher
Salem High School
Salem, IN

Answers to . . .

CHECKPOINT *He used a flask with a long curved neck to allow air, but not microorganisms, to enter the flask.*

Figure 1–11 *The curved neck prevented microorganisms from making their way into the flask. Once the neck of the flask was broken, microorganisms could get to the broth, where the microorganisms multiplied.*

1–2 (continued)

When Experiments Are Not Possible

Build Science Skills

Classifying Have each student write down two topics related to biology that he or she would like to investigate and develop one hypothesis related to each topic. Divide the class into small groups, and ask each group to classify the hypotheses of each of its members according to whether a controlled experiment could be used in testing them. If the answer is no, challenge groups to explain how each hypothesis could be investigated in a way in which scientists could discover reliable patterns that could add to scientific knowledge. L2

How a Theory Develops

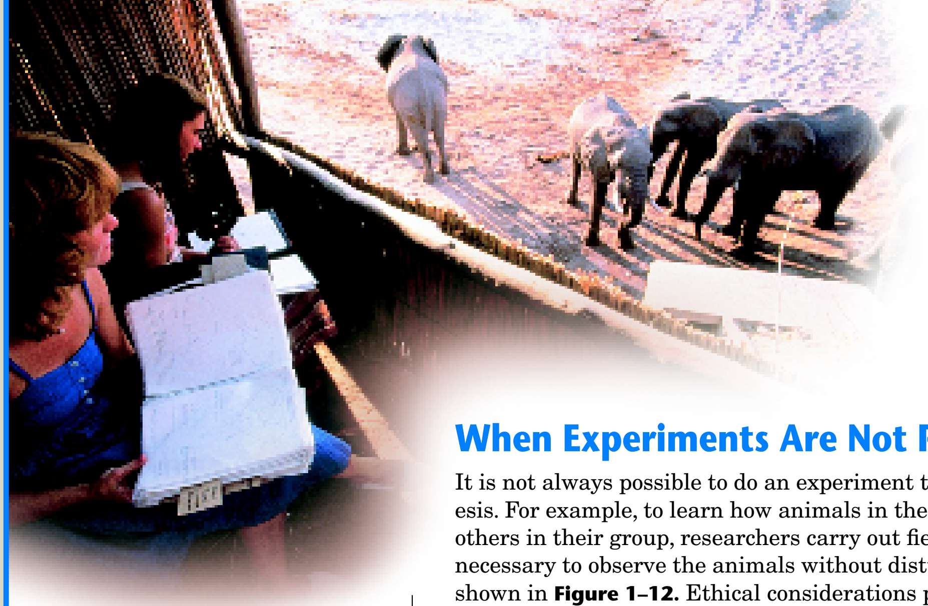
Address Misconceptions

Discuss with students how the word *theory* is used in everyday speech. One dictionary definition of the word lists *conjecture* and *speculation* as synonyms. Point out that people often use the word *theory* when they are really referring to a hypothesis—for example, "I have a theory about why the washing machine doesn't work." L1

Build Science Skills

Comparing and Contrasting Ask students to look for examples from the print or electronic media where the term *theory* is used. Have them determine for each example whether the usage represents the scientific meaning of theory or its meaning in everyday speech. L2

Go Online NSTA SciLinks
Download a worksheet on experimenting for students to complete, and find additional teacher support from NSTA SciLinks.



▲ **Figure 1–12** In animal field studies, such as the observation of wild elephants, scientists usually try to work without making the animals aware that humans are present.
Comparing and Contrasting *How do animal field studies differ from controlled experiments?*

When Experiments Are Not Possible

It is not always possible to do an experiment to test a hypothesis. For example, to learn how animals in the wild interact with others in their group, researchers carry out field studies. It is necessary to observe the animals without disturbing them, as shown in **Figure 1–12.** Ethical considerations prevent certain experiments, such as determining the effect on people of a chemical suspected of causing cancer. In such cases, medical researchers may choose volunteers who have already been exposed to the chemical. For comparison, they would study a group of people who have not been exposed to the chemical.

When researchers design such alternative investigations, they try to maintain the rigorous thinking associated with a controlled experiment. They often study large groups of subjects so that small differences do not produce misleading results. They try to identify as many relevant variables as possible so that most variables are controlled. For example, in a study of a cancer-causing chemical, they might exclude volunteers who have other serious health problems. By exerting great care in planning these kinds of investigations, scientists can discover reliable patterns that add to scientific knowledge.

CHECKPOINT *Why are controlled experiments sometimes impossible?*

How a Theory Develops

As evidence from numerous investigations builds up, a particular hypothesis may become so well supported that scientists consider it a **theory.** That is what happened with the hypothesis that new organisms come from existing organisms. This idea is now considered one of the major ideas in science. It is called biogenesis, meaning "generating from life."

You may have heard the word *theory* used in everyday conversations as people discuss ideas. Someone might say, "Oh, that's just a theory," to criticize an idea that is not supported by evidence. **In science, the word *theory* applies to a well-tested explanation that unifies a broad range of observations.** A theory enables scientists to make accurate predictions about new situations.

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For: Links on experimenting
Visit: www.SciLinks.org
Web Code: cbn-1012

BIO INSIGHTS — FACTS AND FIGURES

An established principle
In common speech, the word *theory* is often used to mean an unverified assumption, in contrast to a fact—something that exists or is known to have happened. In scientific usage, a theory is an overarching generalization that explains, and is supported by, a broad range of observation and experimentation. Thus, the germ theory of disease is not an assumption but an established principle of modern science. This confusion about the meaning of the term is often heard in debates about the theory of evolution, with those who oppose the teaching of that theory attacking it on the basis that it is unproven, or "just a theory." In fact, the opposite is closer to the truth. There is so much evidence for evolution that it has become an established principle, or a scientific theory.

Figure 1–13 **A theory is a well-tested explanation that unifies a broad range of observations.** The theories of plate tectonics and evolution help explain why marsupials such as the koala (top) and kangaroo (below) can be found only in Australia and some nearby islands.

Sometimes, more than one theory is needed to explain a particular circumstance. For example, why are the marsupial mammals in **Figure 1–13** found only in Australia and some nearby islands? An answer lies with the theories of plate tectonics and evolution. Millions of years ago, when marsupials were evolving, Australia, Antarctica, and South America were joined as a single landmass. That landmass began to break apart, and Australia became a separate continent. Its marsupials were thus separated from other kinds of mammals, and they evolved as a unique group. You will study the theory of evolution in Unit 5.

A useful theory may become the dominant view among the majority of scientists, but no theory is considered absolute truth. Scientists analyze, review, and critique the strengths and weaknesses of theories. As new evidence is uncovered, a theory may be revised or replaced by a more useful explanation. Sometimes, scientists resist a new way of looking at nature, but over time new evidence determines which ideas survive and which are replaced. Thus, science is characterized by both continuity and change.

1–2 Section Assessment

1. **Key Concept** Why is Redi's experiment on spontaneous generation considered a controlled experiment?
2. **Key Concept** How does a scientific theory compare with a scientific hypothesis?
3. How do scientists today usually communicate their results and conclusions?
4. How did the design of Pasteur's flask help him successfully refute the hypothesis of spontaneous generation?
5. **Critical Thinking Making Judgments** Evaluate the impact of Pasteur's research on both scientific thought and society. What was the effect of Pasteur's investigations on scientists' ideas and people's lives?

Writing in Science

Critique a Hypothesis
Write a paragraph in which you analyze, review, and critique the spontaneous generation hypothesis. *Hint:* In preparation, ask yourself questions such as these: What observations did the hypothesis account for? Why did it seem logical at that time? What evidence was overlooked or ignored?

1–2 Section Assessment

1. Redi controlled all variables but one—whether or not there was gauze over each jar.
2. A hypothesis is a proposed scientific explanation for a set of observations, whereas a theory is a well-tested explanation that unifies a broad range of observations.
3. They often publish a report of their work in a scientific journal.
4. The curved neck of Pasteur's flask prevented microorganisms from the air from getting into the broth, keeping the broth free of microorganisms. He showed that all living things come from other living things.
5. Pasteur's work represented a major shift in the way scientists viewed living things. He showed that infectious diseases were the result of microorganisms entering bodies, and therefore this discovery set the stage for medical advances that have protected people from diseases.

3 ASSESS

Evaluate Understanding

Have students focus on Pasteur's experiment. Then, call on students at random to state the question Pasteur asked, explain what his hypothesis was, describe his controlled experiment, analyze the results of that experiment, and explain what conclusion he drew.

Reteach

Review Redi's experiment by having students revisit Figure 1–8. Then, have students write a description of the experiment as if they were Redi writing to a colleague. Emphasize that they should ask a question, write a hypothesis, explain how a controlled experiment was set up, analyze the results, and draw a conclusion.

Writing in Science

Students' answers will vary. A good response will describe the hypothesis of spontaneous generation as the idea that life could arise from nonliving matter. Students should explain that this hypothesis seemed valid in light of people's everyday observations—that some living things could just suddenly appear. Any alternative scientific exploration is acceptable. For example, eggs were laid in rotting meat, resulting in maggots.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 1–2.

Answers to . . .

CHECKPOINT *Ethics prevent most experiments with humans. In field studies, researchers try not to disturb animals that they observe.*

Figure 1–12 *In field studies, researchers observe relationships among identified variables but do not manipulate the variables.*