# 1.3 Scientific Thinking and Processes

**VOCABULARY**

- observation
- data
- hypothesis
- experiment
- independent variable
- dependent variable
- constant
- theory

**KEY CONCEPT** **Science is a way of thinking, questioning, and gathering evidence.**

**MAIN IDEAS**

- Like all science, biology is a process of inquiry.
- Biologists use experiments to test hypotheses.
- A theory explains a wide range of observations.

### *Connect to Your World*

What does the study of fungus have in common with the study of human heart disease? How is research in a laboratory similar to research in a rain forest? Biologists, like all scientists, ask questions about the world and try to find answers through observation and experimentation. How do your daily observations help answer questions that you have about the world?

**MAIN IDEA**

## Like all science, biology is a process of inquiry.

Science is a human process of trying to understand the world around us. There is no one method used by all scientists, but all scientific inquiry is based on the same principles. Scientific thinking is based on both curiosity and skepticism. Skepticism is the use of critical and logical thinking to evaluate results and conclusions. Scientific inquiry also requires evidence. One of the most important points of science is that scientific evidence may support or even overturn long-standing ideas. To improve our understanding of the world, scientists share their findings with each other. The open and honest exchange of data is extremely important in science.

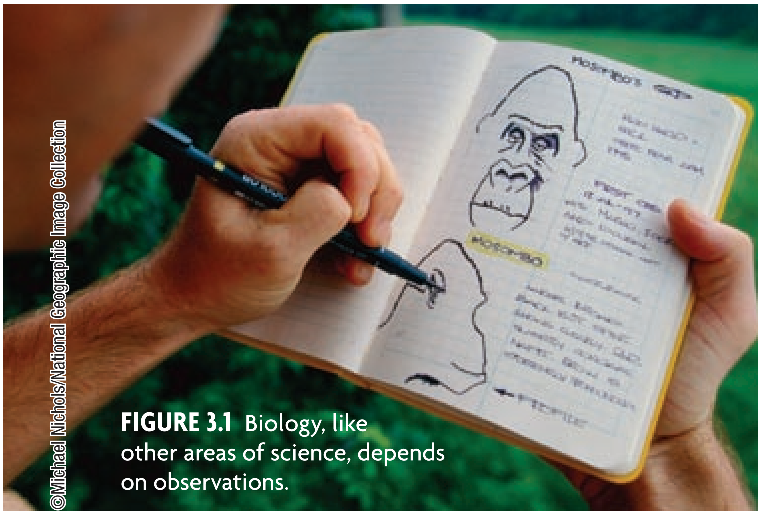




**FIGURE 3.1** Biology, like other areas of science, depends on observations.

### Observations, Data, and Hypotheses

All scientific inquiry begins with careful and systematic observations. Of course, **observation** includes using our senses to study the world, but it may also involve other tools. For example, scientists use computers to collect measurements or to examine past research results. Much early biological research was based on observing, describing, and categorizing the living world. By themselves, description and categorization are not as common in research today because of advances in technology, but they are still very important in biology. For example, how could someone study the interactions of gorillas without observing and describing their behavior, as in **FIGURE 3.1**?

**CONNECT TO**

**DATA ANALYSIS**

Biology relies on the analysis of scientific data. Use the Data Analysis activities in each chapter in this book to build your data analysis skills.

Scientific questions often come from observations, whether the observations are one's own or someone else's. Observations can also be recorded as **data** that can be analyzed. Scientists collect two general types of data: qualitative data and quantitative data. As you learned in the Data Analysis activity, qualitative data are descriptions of a phenomenon that can include sights, sounds, and smells. This type of data is often useful to report what happens but not how it happens. In contrast, quantitative data are characteristics that can be measured or counted, such as mass, volume, and temperature. Anything that is expressed as a number, from time to a rating scale on a survey, is quantitative data that can be used to explore how something happens.

Scientists use observations, data, and scientific literature to form a hypothesis. A **hypothesis** (plural, *hypotheses*) is a proposed answer for a scientific question. A hypothesis must be specific and testable. You probably form and test many hypotheses every day, even though you may not be aware of it. Suppose you oversleep. You needed to get up at 7 A.M., but when you wake up you observe that it is 8 A.M. What happened? Did the alarm not go off? Was it set for the wrong time? Did it go off but you slept through it? You just made three hypotheses to explain why you overslept—the alarm did not go off, the alarm was set for the wrong time, or the alarm went off but you did not hear it.



## Testing Hypotheses

A hypothesis leads to testable predictions of what would happen if the hypothesis is valid. How could you use scientific thinking to test a hypothesis about oversleeping? If you slept late because the alarm was set for the wrong time, you could check the alarm to find out the time for which it was set. Suppose the alarm was actually set for 7 P.M. In this case, your hypothesis would be supported by your data, and you could be certain that the alarm was set for the wrong time.

**FIGURE 3.2** In this experiment, a scientist studies how chemicals are detected in the mouth and nose to produce taste.

For scientists, just one test of a hypothesis is usually not enough. Most of the time, it is only by repeating tests that scientists can be more certain that their results are not mistaken or due to chance. Why? Biological systems are highly variable. By repeating tests, scientists take this variability into account and try to decrease its effects on the experimental results.

After scientists collect data, they use statistics to mathematically analyze whether a hypothesis is supported. There are two possible outcomes of statistical analysis.

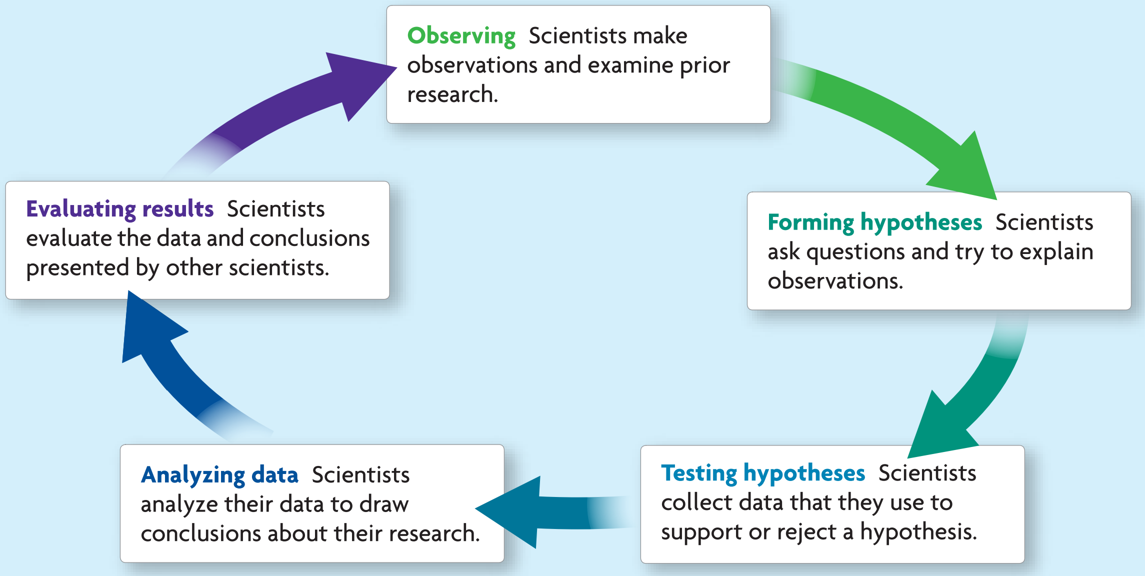
- **Nonsignificant** The data show no effect, or an effect so small that the results could have happened by chance.
- **Statistically significant** The data show an effect that is likely not due to chance.

When data do not support a hypothesis, it is rejected. But these data are still useful because they often lead to new hypotheses.

Experimental methods and results are evaluated by other scientists in a process called peer review. How was an experiment done and how were the data analyzed? Do the data support the conclusions of the experiment?

**FIGURE 3.3 Scientific Thinking**

**Science is a cycle. The steps are shown in a certain order, but the cycle does not begin or end at any one point, and the steps may take place in various orders.**




**Synthesize** **Where in the cycle would retesting a hypothesis fit? Explain.**

Is there bias in the experimental design or in the conclusions? Only after this review process is complete are research results accepted. Whether the results support an existing theory or disagree with earlier research, they are often used as a starting point for new questions. In **FIGURE 3.3**, you see the cycle of observing, forming hypotheses, testing hypotheses, analyzing data, and evaluating results that keeps scientific inquiry going.

**Synthesize** **Why is there no one correct process of scientific investigation?**

MAIN IDEA

## Biologists use experiments to test hypotheses.

You have read about the importance of observations in science. Observational studies help biologists describe and explain something in the world. But in observational studies, scientists try not to interfere with what happens. They try to simply observe a phenomenon. One example involves the endangered white stork. The number of white storks has decreased sharply since 1950. To help protect the storks, biologists have studied the migration patterns of the birds. What can observational studies tell a biologist about stork populations and migration? The studies can show changes in migration path and distance. They can show where storks breed and how many eggs they lay. Observational studies can answer all of these questions. But there is one question that observations cannot answer: What causes any changes that might be observed? The only way to answer that question is through an experiment.

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The Scientific Process

Scientific experiments allow scientists to test hypotheses and find out how something happens. In **experiments,** scientists study factors called independent variables and dependent variables to find cause-and-effect relationships. The **independent variable** in an experiment is a condition that is manipulated, or changed, by a scientist. The effects of manipulating an independent variable are measured by changes in dependent variables. **Dependent variables** are observed and measured during an experiment; they are the experimental data. Changes in dependent variables "depend upon" the manipulation of the independent variable. Suppose a scientist is testing medications to treat high blood pressure. The independent variable is the dose of medication. The dependent variable is blood pressure.

**VISUAL VOCAB**

The **independent variable** is a condition that is manipulated, or changed, by a scientist.

independent variable
↓ affects
dependent variable

**Dependent variables** are observed and measured during an experiment; they are the experimental data.

Ideally, only one independent variable should be tested in an experiment. Thus, all of the other conditions have to stay the same. The conditions that do not change during an experiment are called **constants.** To study the effects of an independent variable, a scientist uses a control group or control condition. Subjects in a control group are treated exactly like experimental subjects except for the independent variable being studied. The independent variable is manipulated in experimental groups or experimental conditions.

**READING TOOLBOX**

**VOCABULARY**

In common usage, the term *constant* means "unchanging." In experimental research, a constant is a condition or factor that is controlled so that it does not change.

Constants in the blood pressure medication experiment include how often the medication is given, and how the medication is taken. To control the experiment, these factors must remain the same, or be held constant. For example, the medication could be tested with 0, 25, 50, or 100 milligram doses, twice a day, taken by swallowing a pill. By changing only one variable at a time—the amount of medication—a scientist can be more confident that the results are due to that variable.

**Infer** **How do experiments show cause-and-effect relationships?**

MAIN IDEA

## A theory explains a wide range of observations.

Many words have several different meanings. Depending on the context in which a word is used, its meaning can change completely. For example, the word *right* could mean "correct," or it could refer to a direction. Similarly, the word *theory* has different meanings. Usually, the word *theory* in everyday conversation means a speculation, or something that is imagined to be true. In science, the meaning of *theory* is very different.

Recall that a hypothesis is a proposed answer for a scientific question. A **theory** is a proposed explanation for a wide range of observations and experimental results that is supported by a wide range of evidence. Eventually, a theory may be broadly accepted by the scientific community.

In contrast, a scientific *law* describes a truth that is valid everywhere in the universe. For example, the law of conservation of energy states that energy may change form but it cannot be created or destroyed. Although this law describes the nature of energy, it does not provide any explanations. Scientific theories provide explanations. For example, natural selection is a scientific theory. It is supported by a large amount of data, and it explains how populations can evolve. Theories are not easily accepted in science, and by definition they are never proved. Scientific hypotheses and theories may be supported or refuted, and they are always subject to change. New theories that better explain observations and experimental results can replace older theories.

One example of how scientific understanding can change involves the cause of disease. Until the mid 1800s, illnesses were thought to be related to supernatural causes or to imbalances of the body's "humours," or fluids. Then scientific research suggested that diseases were caused by microscopic organisms, such as bacteria. The germ theory of disease was born, but it has changed over the years. For example, an early addition to the germ theory stated that it must be possible to grow a disease-causing microorganism in a laboratory. Now we know that viruses and prions do not completely fit the germ theory of disease because they are not living organisms. The link between prions and disease was not even suggested until the early 1980s, but much evidence points to prions as the cause of mad cow disease and, in humans, both classic and variant Creutzfeldt–Jakob disease.

The details of germ theory have changed as our knowledge of biology has grown, but the basic theory is still accepted. Scientists must always be willing to revise theories and conclusions as new evidence about the living world is gathered. Science is an ongoing process. New experiments and observations refine and expand scientific knowledge. Our understanding of the world around us has changed dramatically over the past few decades, and the study of biology has changed and expanded as well.

**Summarize** **What is a scientific theory?**

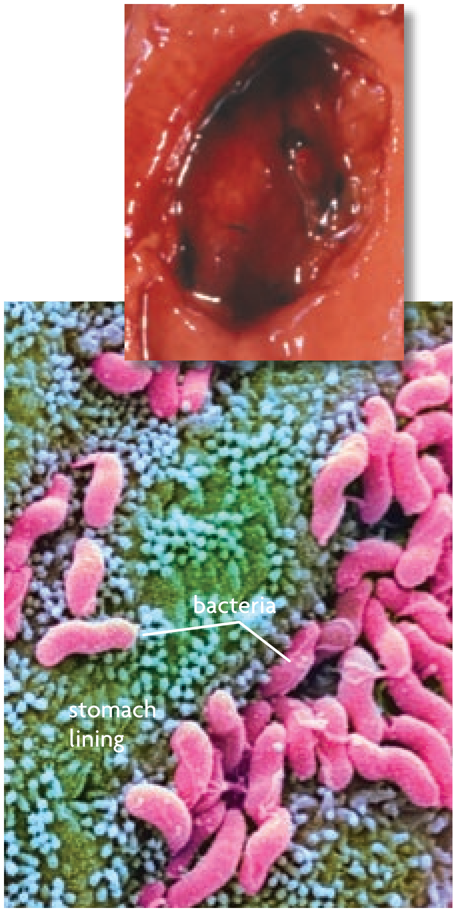


**FIGURE 3.4** For many years, scientific evidence indicated that stomach ulcers (top) were caused by stress. Then new evidence showed that the ulcers are actually caused by a type of bacteria called *Helicobacter pylori* (bottom). (colored SEM; magnification 4000×)



## 1.3 Formative Assessment

### REVIEWING ▶ MAIN IDEAS

1. What role do **hypotheses** play in scientific inquiry?
2. What is the difference between an **independent variable** and a **dependent variable**?
3. How is the meaning of **theory** in science different from the everyday use of the term?

### CRITICAL THINKING

4. **Compare and Contrast** How are hypotheses and theories related?
5. **Apply** Give examples of different ways in which **observations** are used in scientific inquiry.

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### CONNECT TO SCIENTIFIC PROCESS

6. Why is the statement "All life is made of cells" an example of a theory? Explain.