CHAPTER 2

Tools of Environmental Science

1 Scientific Methods
2 Statistics and Models
3 Making Informed Decisions

READING WARM-UP

Before you read this chapter, take a few minutes to answer the following questions in your ***EcoLog.***

1. How is thinking scientifically similar to the usual way you think about things?
2. What are two ways scientists use statistics?

This photograph shows a researcher filming a Weddell seal in Antarctica. Although scientists often use sophisticated tools in their work, their most important tools are those they carry with them—their senses and their habits of mind.

SECTION 1

Scientific Methods

The word *science* comes from the Latin verb *scire,* meaning "to know." Indeed, science is full of amazing facts and ideas about how nature works. But science is not just something you know; it is also something you do. This chapter explores how science is done and examines the tools scientists use.

The Experimental Method

You have probably heard the phrase, "Today scientists discovered…" How do scientists make these discoveries? Scientists make most of their discoveries using the *experimental method.* This method consists of a series of steps that scientists worldwide use to identify and answer questions. The first step is observing.

Observing Science usually begins with observation. Someone notices, or observes, something and begins to ask questions. An **observation** is a piece of information we gather using our senses—our sight, hearing, smell, and touch. To extend their senses, scientists often use tools such as rulers, microscopes, and even satellites. For example, a ruler provides our eyes with a standard way to compare the lengths of different objects. The scientists in **Figure 1** are observing the tail length of a tranquilized wolf with the help of a tape measure. Observations can take many forms, including descriptions, drawings, photographs, and measurements.

Students at Keene High School in New Hampshire have observed that dwarf wedge mussels are disappearing from the Ashuelot River, which is located near their school. The students have also observed that the river is polluted. These observations prompted the students to take the next step in the experimental method—forming hypotheses.

Figure 1 ▶ These scientists are measuring the tail of a tranquilized wolf. What questions could these observations help the scientists answer?

Objectives

- ▶ List and describe the steps of the experimental method.
- ▶ Describe why a good hypothesis is not simply a guess.
- ▶ Describe the two essential parts of a good experiment.
- ▶ Describe how scientists study subjects in which experiments are not possible.
- ▶ Explain the importance of curiosity and imagination in science.

Key Terms

observation
hypothesis
prediction
experiment
variable
experimental group
control group
data
correlation

QuickLAB

Hypothesizing and Predicting

Procedure

1. Place a **baking tray** on a table, and place a **thin book** under one end of the tray.
2. Place **potting soil**, **sand**, and **schoolyard dirt** in three piles at the high end of the baking tray.
3. Use a **toothpick** to poke several holes in a **paper cup.**
4. Write down a hypothesis to explain why soil gets washed away when it rains.
5. Based on your hypothesis, predict which of the three soils will wash away most easily.
6. Pour **water** into the cup, and slowly sprinkle water on the piles.

Analysis

1. What happened to the different soils?
2. Revise your hypothesis, if necessary, based on your experiment.

Hypothesizing and Predicting Observations give us answers to questions, but observations almost always lead to more questions. To answer a specific question, a scientist may form a hypothesis. A **hypothesis** (hie PAHTH uh sis) is a testable explanation for an observation. A hypothesis is more than a guess. A good hypothesis should make logical sense and follow from what you already know about the situation.

The Keene High School students observed two trends: that the number of dwarf wedge mussels on the Ashuelot River is declining over time and that the number of dwarf wedge mussels decreases at sites downstream from the first study site. These trends are illustrated in **Figure 2.** Students tested the water in three places and found that the farther downstream they went, the more phosphate the water contained. Phosphates are chemicals used in many fertilizers.

Armed with their observations, the students might make the following hypothesis: *phosphate fertilizer from a golf course is washing into the river and killing dwarf wedge mussels*. To test their hypothesis, the students make a **prediction,** a logical statement about what will happen if the hypothesis is correct. The students might make the following prediction: *mussels will die when exposed to high levels of phosphate in their water*.

It is important that the students' hypothesis—high levels of phosphate are killing the mussels—can be disproved. If students successfully raised mussels in water that has high phosphate levels, their hypothesis would be incorrect. Every time a hypothesis is disproved, the number of possible explanations for an observation is reduced. By eliminating possible explanations a scientist can zero in on the best explanation with more confidence.

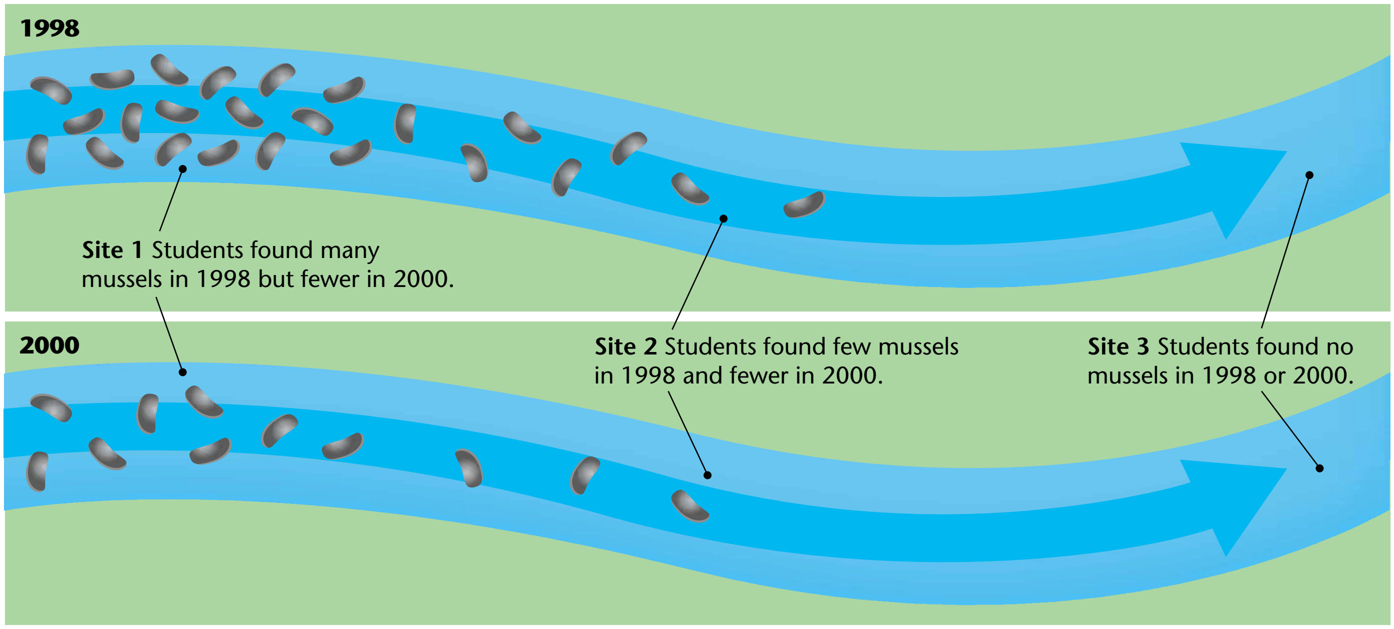

Figure 2 ▶ The diagram below illustrates the trends observed by the students at Keene High School.

Experimenting The questions that arise from observations often cannot be answered by making more observations. In this situation scientists usually perform one or more experiments. An **experiment** is a procedure designed to test a hypothesis under controlled conditions.

Experiments should be designed to pinpoint cause-and-effect relationships. For this reason, good experiments have two essential characteristics: a single variable is tested, and a control is used. The **variable** (VER ee uh buhl) is the factor of interest, which, in our example, would be the level of phosphate in the water. To test for one variable, scientists usually study two groups or situations at a time. The variable being studied is the only difference between the groups. The group that receives the experimental treatment is called the **experimental group.** In our example, the experimental group would be those mussels that receive phosphate in their water. The group that does not receive the experimental treatment is called the **control group.** In our example, the control group would be those mussels that do not have phosphate added to their water. If the mussels in the control group thrive while most of those in the experimental group die, the experiment's results support the hypothesis that phosphates from fertilizer are killing the mussels.

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CASE STUDY

The Experimental Method In Action at Keene High School

▶ **Keene High School** students are conducting an experiment to study the effect of phosphate levels on the growth rates of freshwater mussels.

Keene High School students collected mussels (nonendangered relatives of the dwarf wedge mussel) and placed equal numbers of them in two aquariums. They ensured that the conditions in the aquariums were identical—same water temperature, food, hours of light, and so on. The students added a measured amount of phosphate to the aquarium of the experimental group. They added nothing to the aquarium of the control group.

A key to the success of an experiment is changing only one variable and having a control group. What would happen if the aquarium in which most of the mussels died had phosphate in the water and was also warmer? The students would not know if the phosphate or the higher temperature killed the mussels.

Another key to experimenting in science is *replication*, or recreating the experimental conditions to make sure the results are consistent. In this case, using six aquariums—three control and three experimental—would help ensure that the results are not simply due to chance.

CRITICAL THINKING

1. Applying Ideas Why did the students ensure that the conditions in both aquariums were identical?

2. Evaluating Hypothesis How would you change the hypothesis if mussels died in both aquariums?

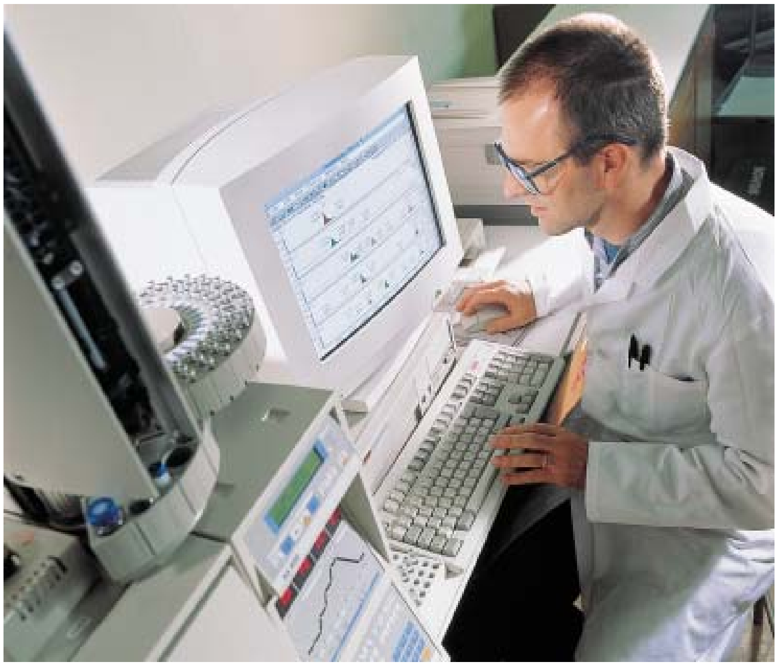


Figure 3 ▶ This scientist is analyzing his data with the help of a computer.

Organizing and Analyzing Data Keeping careful and accurate records is extremely important in science. A scientist cannot rely on experimental results that are based on sloppy observations or incomplete records. The information that a scientist gathers during an experiment, which is often in numeric form, is called **data.**

Organizing data into tables and graphic illustrations helps scientists analyze the data and explain the data clearly to others. The scientist in **Figure 3** is analyzing data on pesticides in food. Graphs are often used by scientists to display relationships or trends in the data. For this reason, graphs are especially useful for illustrating conclusions drawn from an experiment.

One common type of graph is called a *bar graph*. Bar graphs are useful for comparing the data for several things in one graph. The bar graph in **Figure 4** displays the information contained in the table above it. Graphing the information makes the trends easy to see. The graph shows that phosphates decrease downstream and that nitrates increase downstream.

Table 1 ▼

Pollutant Concentrations		
Site	Nitrates	Phosphates
1	0.3	0.02
2	0.3	0.06
3	0.1	0.07

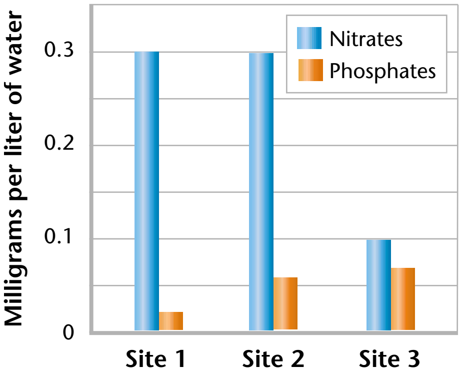


Figure 4 ▶ The table (top) presents data on the amount of phosphates and nitrates found at Sites 1, 2, and 3 on the Ashuelot River in 2000. The bar graph (bottom) displays this information in graphical form.

Drawing Conclusions Scientists determine the results of their experiment by analyzing their data and comparing the outcome of their experiment with their prediction. Ideally, this comparison provides the scientist with an obvious conclusion. But often the conclusion is not obvious. For example, in the mussel experiment, what if three mussels died in the control tank and five died in the experimental tank? The students could not be certain that phosphate is killing the mussels. Scientists often use mathematical tools to help them determine whether such differences are meaningful or are just a coincidence. Scientists also repeat their experiments.

Repeating Experiments Although the results from a single experiment may seem conclusive, scientists look for a large amount of supporting evidence before they accept a hypothesis. The more often an experiment can be repeated with the same results, in different places and by different people, the more sure scientists become about the reliability of their conclusions.

Communicating Results Scientists publish their results to share what they have learned with other scientists. When scientists think their results are important, they usually publish their findings as a scientific article. A scientific article includes the question the scientist explored, reasons why the question is important, background information, a precise description of how the work was done, the data that were collected, and the scientist's interpretation of the data.

The Correlation Method

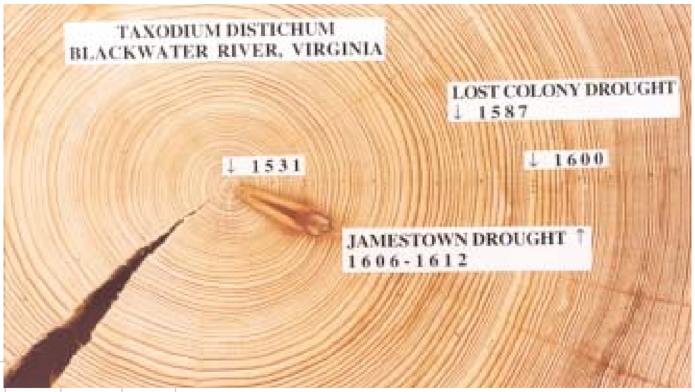
Whenever possible, scientists study questions by using experiments. But many questions cannot be studied experimentally. The question "What was Earth's climate like 60 million years ago?" cannot be studied by performing an experiment because the scientists are 60 million years too late. "Does smoking cause lung cancer in humans?" cannot be studied experimentally because doing experiments that injure people would be unethical.

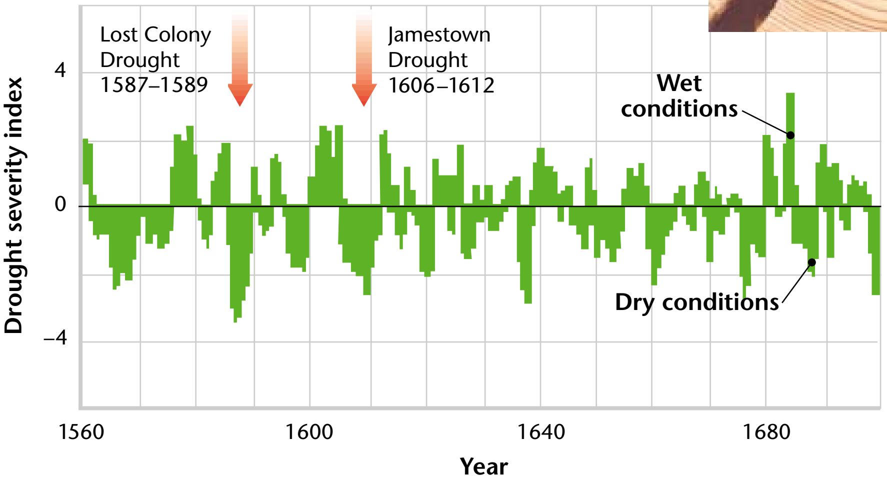
When using experiments to answer questions is impossible or unethical, scientists test predictions by examining **correlations,** or reliable associations between two or more events. For example, scientists know that the relative width of a ring on a tree trunk is a good indicator of the amount of rainfall the tree received in a given year. Trees produce wide rings in rainy years and narrow rings in dry years. Scientists have used this knowledge to investigate why the first European settlers at Roanake Island, Virginia (often called the Lost Colony) disappeared and why most of the first settlers at Jamestown, Virginia, died. As shown in **Figure 5,** the rings of older trees on the Virginia coast indicate that the Lost Colony and the Jamestown Colony were founded during two of the worst droughts the coast had experienced in centuries. The scientists concluded that the settlers may have been the victims of unfortunate timing.

Although correlation studies are useful, correlations do not necessarily prove cause-and-effect relationships between two variables. For example, the correlation between increasing phosphate levels and a declining mussel population on the Ashuelot River does not prove that phosphates harm mussels. Scientists become more sure about their conclusions if they find the same correlation in different places and as they eliminate possible explanations.

Connection to Geology

Coral Correlation Some geologists use an interesting correlation to study records of past climates. Certain species of coral put down layers of skeleton every year and can live for 300 years. Coral skeletons contain the elements strontium, Sr, and calcium, Ca. In some corals, the ratio of these elements in a layer of skeleton correlates with local sea surface temperatures at the time that layer forms. The correlation between the Sr to Ca ratio and the sea temperature provides scientists with one record of how Earth's climate has changed over the centuries.





Source: *Science.*

Figure 5 ▶ This cross section of a baldcypress from southeastern Virginia (above) shows a record of rainfall beginning in 1531. The graph translates the relative tree ring width into what is called a *drought index,* which allowed scientists to compare rainfall between different years.

Connection to Biology

Discovering Penicillin Alexander Fleming discovered penicillin by accident. Someone left a window open near his dishes of bacteria, and the dishes were infected with spores of fungi. Instead of throwing the dishes away, Fleming looked at them closely and saw that the bacteria had died on the side of a dish where a colony of green *Penicillium* mold had started to grow. If he had not been a careful observer, penicillin might not have been discovered. You may find *Penicillium* yourself on moldy bread.

Scientific Habits of Mind

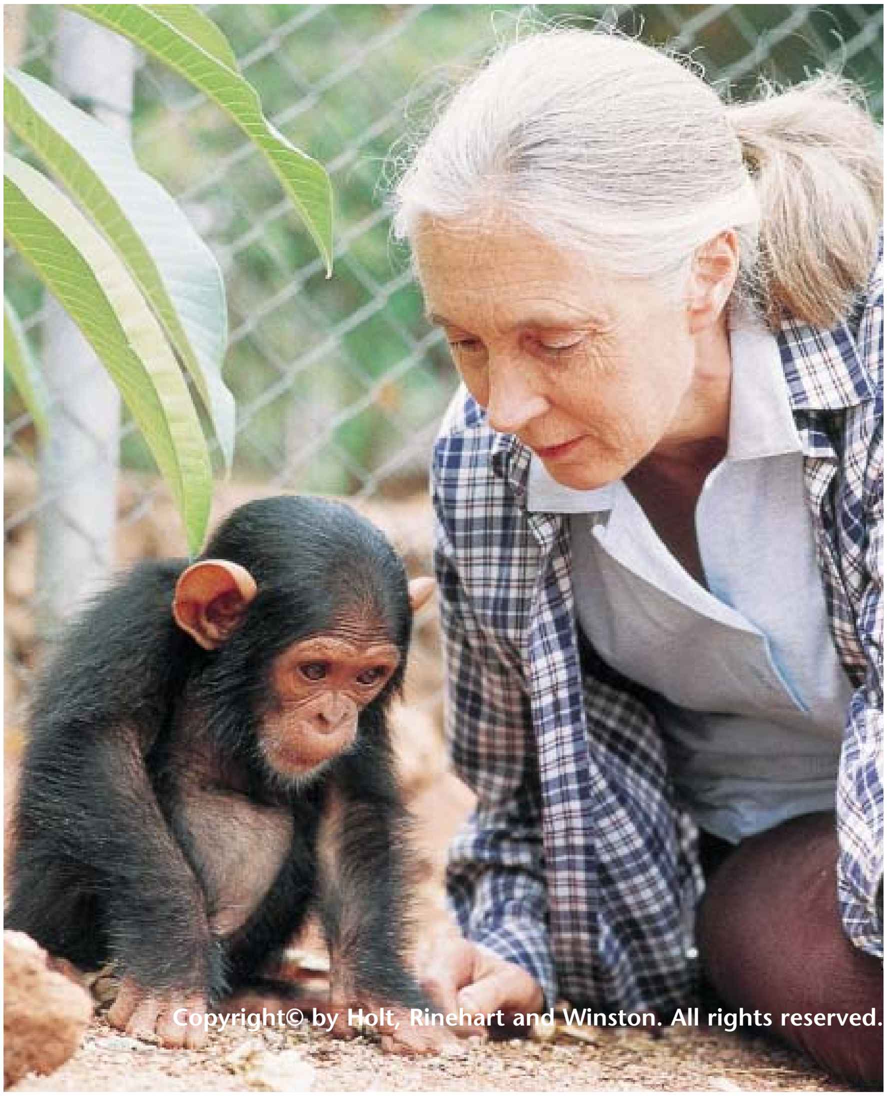
Scientists actually approach questions in many different ways. But good scientists tend to share several key habits of mind, or ways of approaching and thinking about things.

Curiosity Good scientists are endlessly curious. Jane Goodall, pictured in **Figure 6,** is an inspiring example. She studied a chimpanzee troop in Africa for years. She observed the troop so closely that she came to know the personalities and behavior of each member of the troop and greatly contributed to our knowledge of that species.

The Habit of Skepticism Good scientists also tend to be skeptical, which means that they don't believe everything they are told. For example, 19th century doctors were taught that men and women breathe differently—men use the diaphragm (the sheet of muscle below the rib cage) to expand their chests, whereas women raise their ribs near the top of their chest. Finally, a female doctor found that women seemed to breathe differently because their clothes were so tight that their ribs could not move far enough to pull air into their lungs.

Openness to New Ideas As the example above shows, skepticism can go hand in hand with being open to new ideas. Good scientists keep an open mind about how the world works.

Figure 6 ▶ Jane Goodall is famous for her close observations of chimpanzees—observations fueled in part by her endless curiosity.



Intellectual Honesty A scientist may become convinced that a hypothesis is correct even before it has been fully tested. But when an experiment is repeated, the results may be different from those obtained the first time. A good scientist is willing to recognize that the new results may be accurate, even though that means admitting that his or her hypothesis might be wrong.

Imagination and Creativity Good scientists are not only open to new ideas but able to conceive of new ideas themselves. The ability to see patterns where others do not or imagine things that others cannot allows a good scientist to expand the boundaries of what we know.

An example of an imaginative and creative scientist is John Snow, shown in **Figure 7**. Snow was a physician in London during a cholera epidemic in 1854. Cholera, a potentially fatal disease, is caused by a bacterium found in water that is polluted with human waste. Few people had indoor plumbing in 1854. Most people got their water from public pumps; each pump had its own well. In an attempt to locate the polluted water source, Snow made a map showing where the homes of everyone who died of cholera were located. The map also showed the public water pumps. In an early example of a correlation study, he found that more deaths occurred around a pump in Broad Street than around other pumps in the area. London authorities ended the cholera epidemic by taking the handle off the Broad Street pump so that it could no longer be used. Using observation, imagination, and creativity, Snow solved an environmental problem and saved lives.

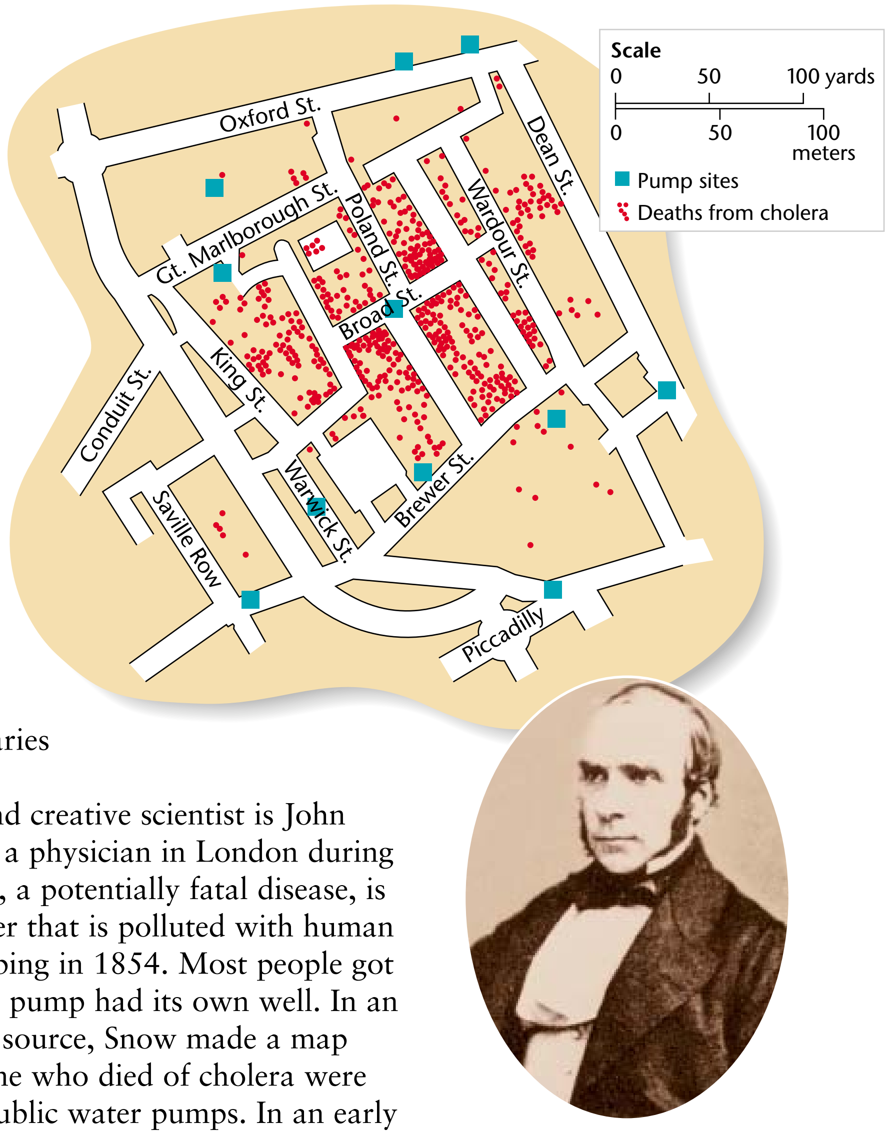


Figure 7 ▶ John Snow (bottom) created his famous spot map (top), which enabled him to see a pattern no one had noticed before.

SECTION 1 Review

1. **Describe** the steps of the experimental method.
2. **Name** and explain the importance of three scientific habits of mind.
3. **Explain** why a hypothesis is not just a guess.
4. **Explain** how scientists try to answer questions that cannot be tested with experiments.

CRITICAL THINKING

5. **Analyzing Methods** Read the description of experiments. Describe the two essential parts of a good experiment, and explain their importance. **READING SKILLS**
6. **Analyzing Relationships** How can a scientist be both skeptical and open to new ideas at the same time? Write a one-page story that describes such a situation. **WRITING SKILLS**