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 more 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.

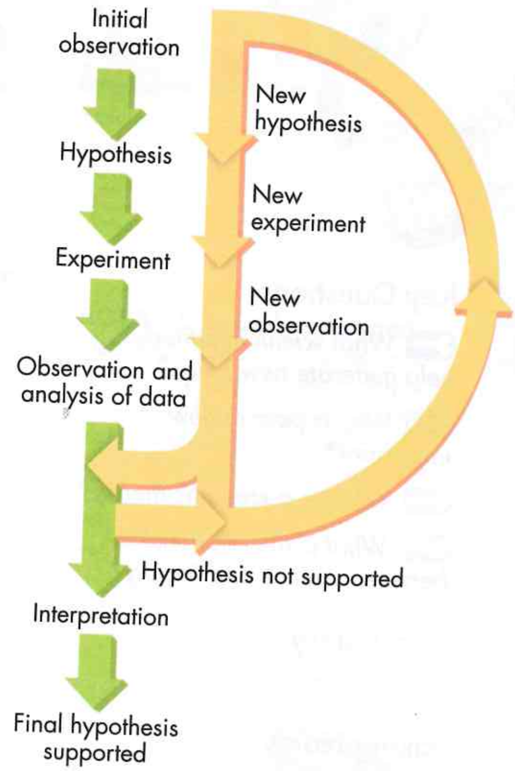

FIGURE 1–4 Revising Hypotheses During the course of an investigation, hypotheses may have to be revised and experiments redone several times.

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?

WRITE ABOUT SCIENCE

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?

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1.2 Science in Context

Key Questions

What scientific attitudes help generate new ideas?

Why is peer review important?

What is a scientific theory?

What is the relationship between science and society?

Vocabulary

theory • bias

Taking Notes

Preview Visuals Before you read, study **Figure 1–10.** As you read, use the figure to describe the role science plays in society.

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

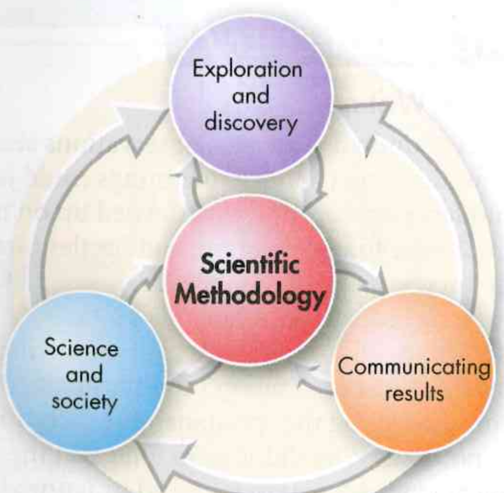
What scientific attitudes help generate new ideas?

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.

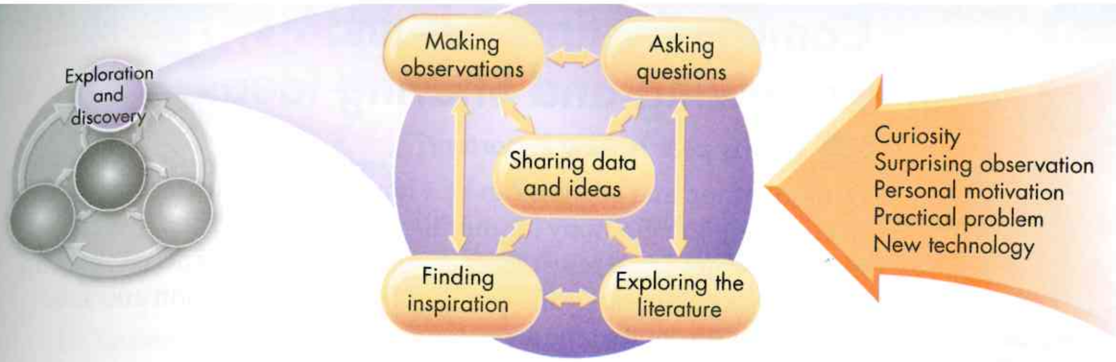
Scientific Attitudes Good scientists share scientific attitudes, or habits of mind, that lead them to exploration and discovery. **Curiosity, skepticism, open-mindedness, and creativity help scientists generate new ideas.**

- ***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.

FIGURE 1–5 The Process of Science As the arrows indicate, the different aspects of science are interconnected—making the process of science dynamic, flexible, and unpredictable.



Adapted from *Understanding Science*, UC Berkeley, Museum of Paleontology

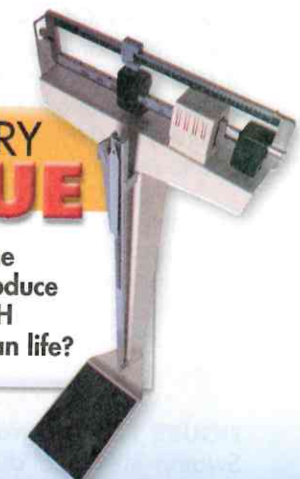


Adapted from *Understanding Science,* UC Berkeley, Museum of Paleontology

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.

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 before were only available naturally.

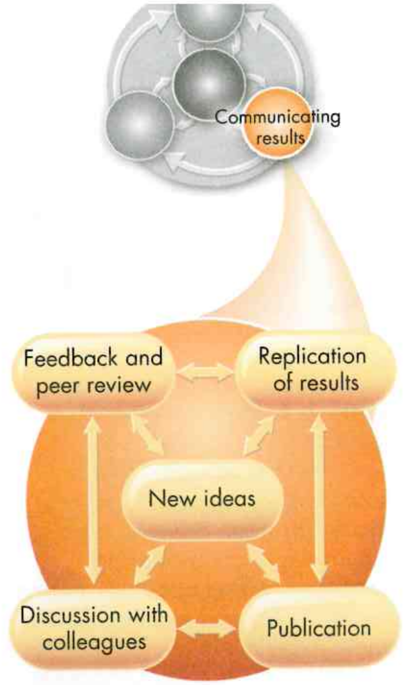


MYSTERY CLUE

How does the ability to produce artificial HGH impact human life?

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

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?***



Adapted from *Understanding Science*, UC Berkeley, Museum of Paleontology

FIGURE 1–8 Communicating Results Communication is an important part of science. Scientists review and evaluate one another's work to ensure accuracy. Results from one study may lead to new ideas and further studies.

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.*

FIGURE 1–9 Mangrove Swamp In tropical areas, mangrove swamps serve as the ecological equivalents of temperate salt marshes. The results of the salt marsh experiment suggest that nitrogen might be a limiting nutrient for mangroves and other plants in these similar habitats. **Design an Experiment** *How would you test this hypothesis?*

GUIDED INQUIRY

Replicating Procedures

1. Working with a partner behind a screen, assemble ten blocks into an unusual structure. Write directions that others can use to replicate that structure without seeing it.
2. Exchange directions with another team. Replicate the team's structure by following its directions.
3. Compare each replicated structure to the original. Identify which parts of the directions were clear and accurate, and which were unclear or misleading.

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?

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.

BUILD Vocabulary

ACADEMIC WORDS A scientific **theory** describes a well-tested explanation for a range of phenomena. Scientific theories are different from scientific laws and it is important to understand that theories do not *become* laws. Laws, such as ideal gas laws in chemistry or Newton's laws of motion, are concise, specific descriptions of how some aspect of the natural world is expected to behave in a certain situation. In contrast, scientific theories, such as cell theory or the theory of evolution, are more dynamic and complex. Scientific theories encompass a greater number of ideas and hypotheses than laws, and are constantly fine-tuned through the process of science.

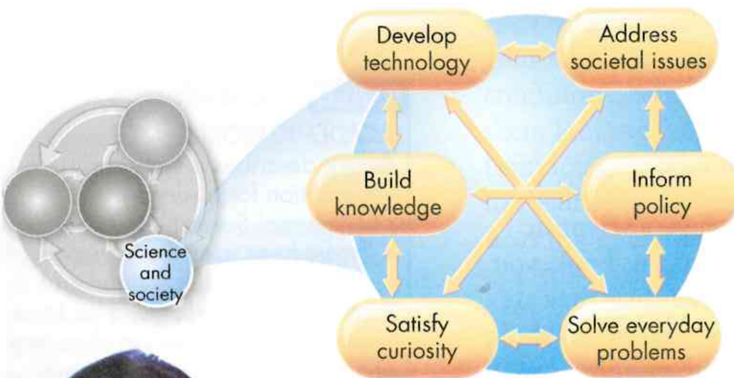
Science and Society

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.

FIGURE 1–10 Science and Society Science both influences society and is influenced by society. The researcher below tests shellfish for toxins that can poison humans. **Form an Opinion** ***Should shellfish be routinely screened for toxins?***



Adapted from *Understanding Science*, UC Berkeley, Museum of Paleontology

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.

Understanding and Using Science Science will keep changing as long as humans keep wondering about nature. We invite you to join us in that wonder and exploration as you read this book. Think of this text, not as an encyclopedia, but as a "user's guide" to the study of life. Don't just memorize today's scientific facts and ideas. And please don't *believe* them! Instead, try to *understand* how scientists developed those ideas. Try to see the thinking behind experiments we describe. Try to pose the kinds of questions scientists ask.

If you learn to think as scientists think, you will understand the process of science and be comfortable in a world that will keep changing throughout your life. Understanding science will help you make complex decisions that also involve cultural customs, values, and ethical standards.

Furthermore, understanding biology will help you realize that we humans can predict the consequences of our actions and take an active role in directing our future and that of our planet. In our society, scientists make recommendations about big public policy decisions, but they don't make the decisions. Who makes the decisions? Citizens of our democracy do. In a few years, you will be able to exercise the rights of a voting citizen, influencing public policy by the ballots you cast and the messages you send public officials. That's why it is important that you understand how science works and appreciate both the power and the limitations of science.

FIGURE 1–11 Using Science in Everyday Life These student volunteers are planting mangrove saplings as part of a mangrove restoration project.

1.2 Assessment

Review Key Concepts

1. a. Review List the attitudes that lead scientists to explore and discover.

b. Explain What does it mean to describe a scientist as skeptical? Why is skepticism an important quality in a scientist?

2. a. Review What is peer review?

b. Apply Concepts An advertisement claims that studies of a new sports drink show it boosts energy. You discover that none of the study results have been peer-reviewed. What would you tell consumers who are considering buying this product?

3. a. Review What is a scientific theory?

b. Compare and Contrast How does use of the word *theory* differ in science and in daily life?

4. a. Review How is the use of science related to its context in society?

b. Explain Describe some of the limitations of science.

c. Apply Concepts A study shows that a new pesticide is safe for use on food crops. The researcher who conducted the study works for the pesticide company. What potential biases may have affected the study?

Apply the Big idea

Science as a Way of Knowing

5. Explain in your own words why science is considered a "way of knowing."

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