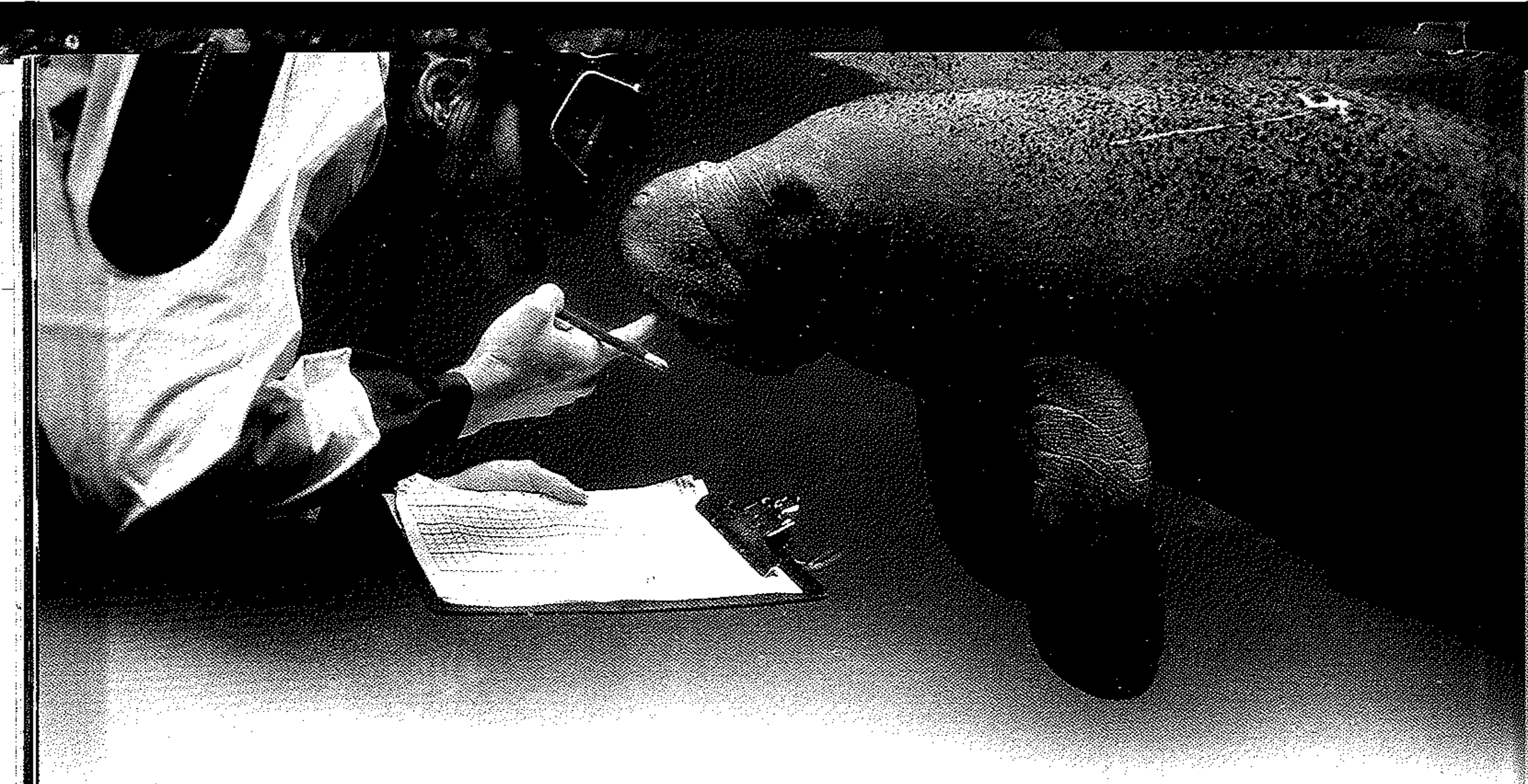


▲ **Figure 1–2** **The goal of science is to investigate and understand nature.** The first step in this process is making observations. This researcher is observing the behavior of a manatee in Florida.

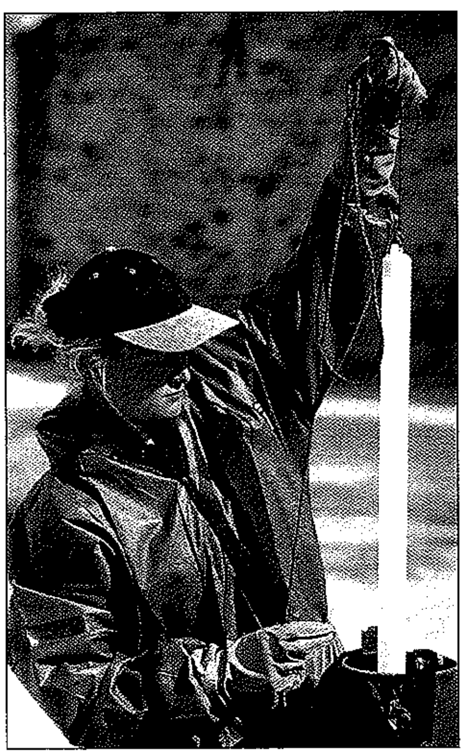
## Thinking Like a Scientist

Suppose a car won't start. Is the car out of gas? A glance at the fuel gauge tests that idea. Perhaps the battery is dead. An auto mechanic can use an instrument to test that idea. To figure out what is wrong with the car, people perform tests and observe the results of the tests.

This familiar activity uses the approach scientists take in research. Scientific thinking usually begins with **observation,** the process of gathering information about events or processes in a careful, orderly way. Observation generally involves using the senses, particularly sight and hearing. The information gathered from observations is called **data.**

There are two main categories of data. Quantitative data are expressed as numbers, obtained by counting or measuring. The researcher in **Figure 1–2,** for example, might note that the manatee "has one scar on its back." Qualitative data are descriptive and involve characteristics that can't usually be counted. The researcher might make the qualitative observations that "the scar appears old" and "the animal seems healthy and alert."

Scientists may use data to make inferences. An **inference** is a logical interpretation based on prior knowledge or experience. The researcher in **Figure 1–3,** for example, is testing water in a reservoir. Because she cannot test *all* the water, she collects water samples from several different parts of the reservoir. If all the samples are clean enough to drink, she may infer that all the water is safe to drink.



◀ **Figure 1–3** Researchers testing water for lead pollution cannot test every drop, so they check small amounts, called samples. **Inferring** *How might a local community use such scientific information?*

## Explaining and Interpreting Evidence

Scientists try to explain events in the natural world by interpreting evidence logically and analytically. Suppose, for example, that many people contract an unknown disease after attending a public event. Public health researchers will use scientific methods to try to determine how those people became ill.

After initial observations, the researchers will propose one or more hypotheses. A **hypothesis** is a proposed scientific explanation for a set of observations. Scientists generate hypotheses using prior knowledge, or what they already know; logical inference; and informed, creative imagination. For the unknown disease, there might be several competing hypotheses, such as these: (1) The disease was spread from person to person by contact. (2) The disease was spread through insect bites. (3) The disease was spread through air, water, or food.

Scientific hypotheses must be proposed in a way that enables them to be tested. Some hypotheses are tested by performing controlled experiments, as you will learn in the next section. Other hypotheses are tested by gathering more data. In the case of the mystery illness, data would be collected by studying the location of the event; by examining air, water, and food people were exposed to; and by questioning people about their actions before falling ill. Some hypotheses would be ruled out. Others might be supported and eventually confirmed.

Researchers working on complex questions often collaborate in teams like the one in **Figure 1–4.** These groups have regular meetings at which they analyze, review, and critique each other's data and hypotheses. This review process helps ensure that their conclusions are valid. To be valid, a conclusion must be based on logical interpretation of reliable data. To learn about sources of error in scientific investigations, see Appendix A.

CHECKPOINT *How do scientists develop hypotheses?*

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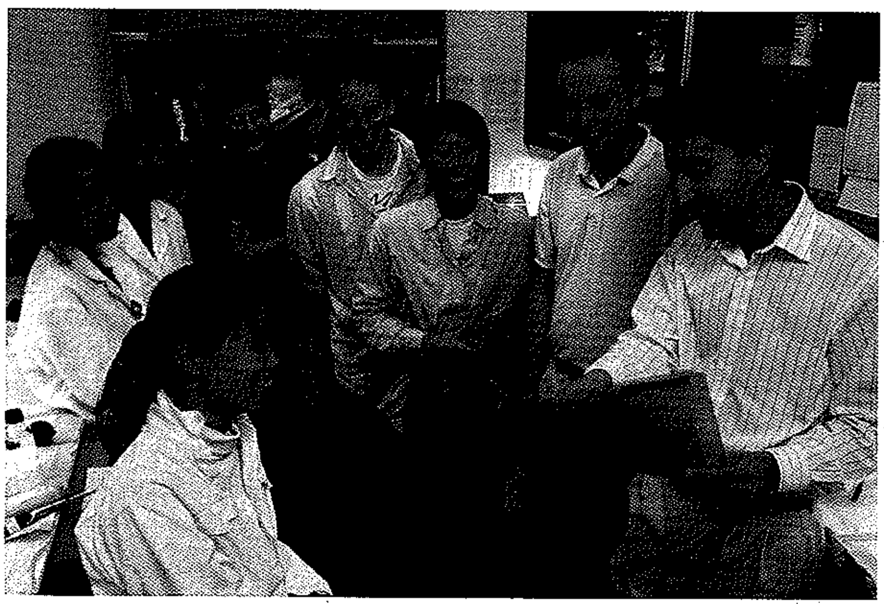


◀ **Figure 1–4** Researchers often collaborate by working in teams, combining imagination and logic to develop and test hypotheses. **Applying Concepts** *How do scientists decide whether to accept or reject a hypothesis?*

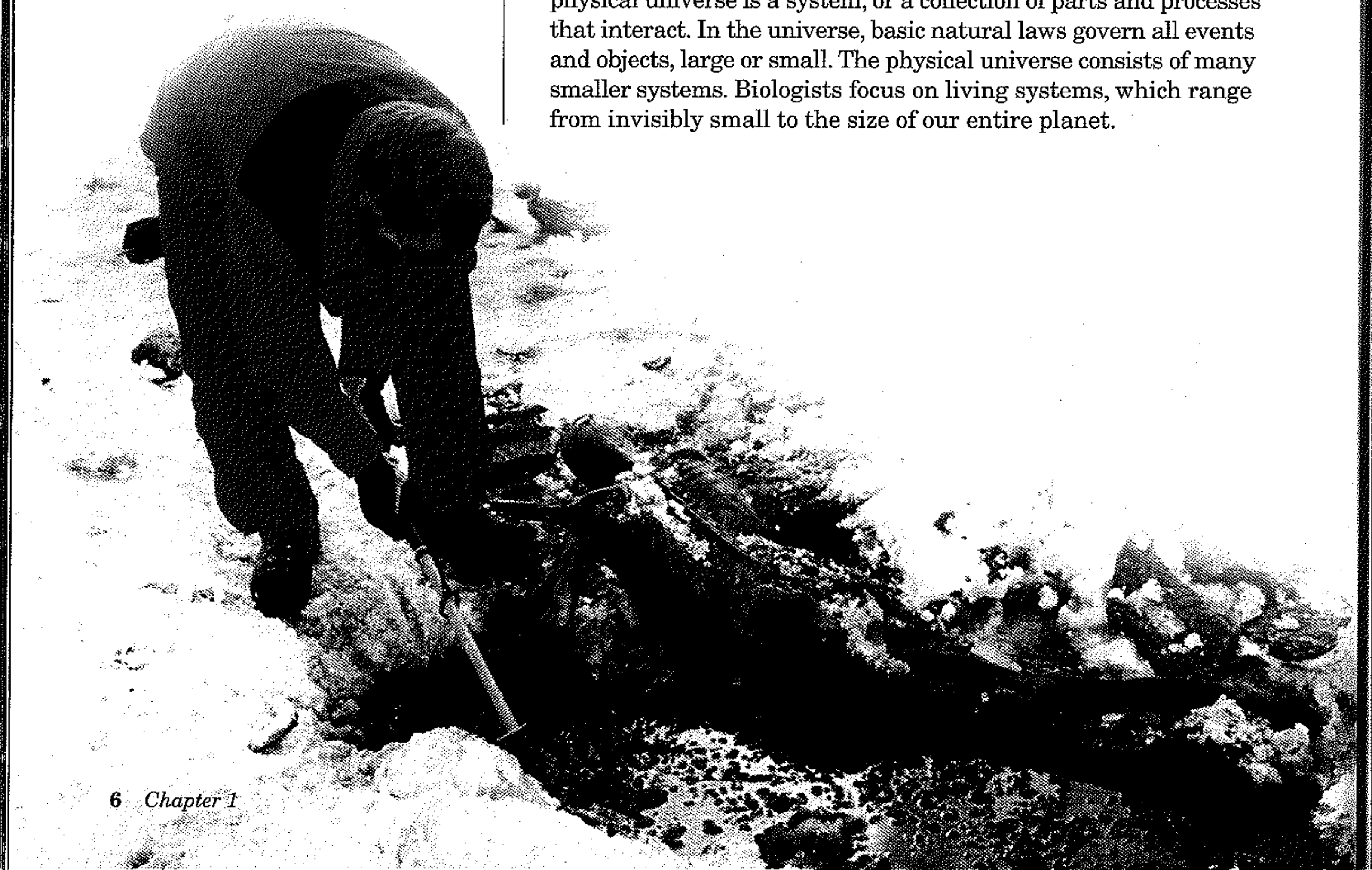
# Science as a Way of Knowing

This book contains lots of facts, but don't think biological science is a set of truths that never change. Instead, science is a way of knowing. This means that rather than unchanging knowledge, science is an ongoing *process*—a process that involves asking questions, observing, making inferences, and testing hypotheses. You can learn more about these and other science skills in Appendix A.

Because of new tools, techniques, and discoveries, such as the discovery shown in **Figure 1–5,** scientific understanding is always changing. Research can have a profound impact on scientific thought. For example, the discovery of cells revolutionized understanding of the structure of living things. Without doubt, some things you learn from this book will soon be revised because of new information. But this doesn't mean that science has failed. On the contrary, it means that science continues to succeed in advancing understanding.

Good scientists are skeptics, which means that they question both existing ideas and new hypotheses. Scientists continually evaluate the strengths and weaknesses of hypotheses. Scientists must be open-minded and consider new hypotheses if data demand it. And despite the power of science, it has definite limits. For example, science cannot help you decide whether a painting is beautiful or whether school sports teams should be limited to only the best athletes.

The scientific way of knowing includes the view that the whole physical universe is a system, or a collection of parts and processes that interact. In the universe, basic natural laws govern all events and objects, large or small. The physical universe consists of many smaller systems. Biologists focus on living systems, which range from invisibly small to the size of our entire planet.



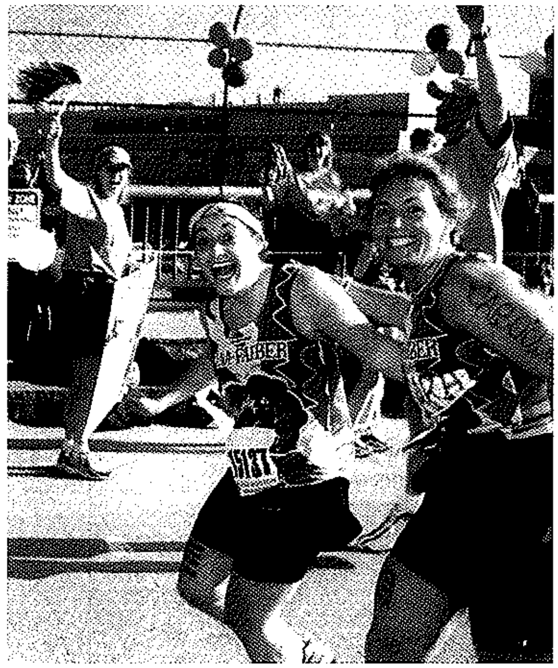
▼ **Figure 1–5** In 1991, hikers in the Italian Alps discovered a well-preserved corpse that was about 5000 years old. Scientists might have asked how the corpse could be so well preserved, but they already knew the answer. Sub-zero temperatures keep the organisms that cause decomposition from doing their job. **Asking Questions** *What are some other scientific questions that might be asked about this discovery?*

## Science and Human Values

Because of new knowledge gained through research, scientists continually revise and re-evaluate their ideas. The importance of science, however, reaches far beyond the scientific world. Today, scientists contribute information to discussions about health and disease, and about the relationship between human beings and the living and nonliving environment.

Make a list of things that you need to understand to protect your life and the lives of others close to you. Chances are that your list will include drugs and alcohol, smoking and lung disease, AIDS, cancer, and heart disease. Other questions focus on public health and the environment. How can we best use antibiotics to make sure that those "wonder drugs" keep working for a long time? How much of the information in your genes should you be able to keep private? Should communities produce electricity using fossil fuels, nuclear power, or hydroelectric dams? How should chemical wastes be disposed of? Who should be responsible for their disposal?

All of these questions involve scientific information. For that reason, an understanding of science and the scientific approach is essential to making intelligent decisions about them. None of these questions, however, can be answered by science alone. They involve the society in which we live and the economy that provides jobs, food, and shelter. They may require us to consider laws and moral principles. In our society, scientists alone do not make final decisions—they make recommendations. Who makes the decisions? We, the citizens of our democracy do—when we vote to express our opinions to elected officials. That is why it is more important than ever that everyone understand what science is, what it can do, and what it cannot do.



▲ **Figure 1–6** Scientific research has an impact on many aspects of our lives. These racers are raising money to help support research directed at preventing and treating cancer. **Applying Concepts** *Identify three ways in which science affects your life.*

## 1–1 Section Assessment

1. **Key Concept** What does science study?
2. What does it mean to describe a scientist as skeptical? Why is skepticism considered a valuable quality in a scientist?
3. What is the main difference between qualitative and quantitative observations?
4. What is a scientific hypothesis? In what two ways can a hypothesis be tested?
5. Is a scientific hypothesis accepted if there is no way to demonstrate that the hypothesis is wrong? Explain your answer.
6. **Critical Thinking Making Judgments** Suppose a community proposes a law to require the wearing of seatbelts in all moving vehicles. How could scientific research have an impact on the decision?

### Alternative Assessment

**Table of Observations and Inferences**
List the five main senses—vision, hearing, smell, taste, and touch—and give an example of an observation that you have made using each sense. Then, add at least one inference that could be made based on each observation.

# 1–2 How Scientists Work

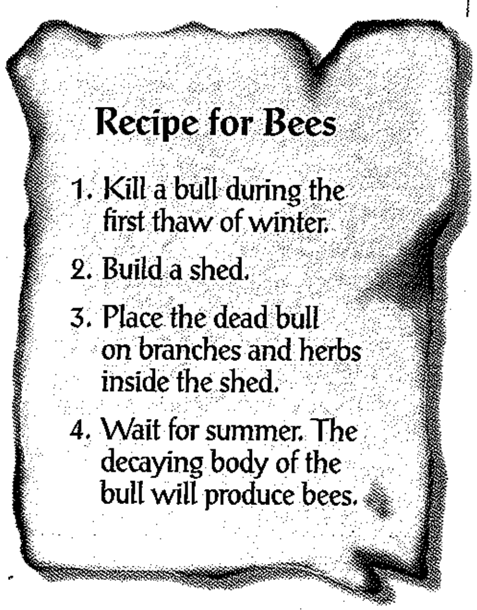
## *Guide for Reading*

**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.

**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?*

▼ **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 (photograph, below). 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**

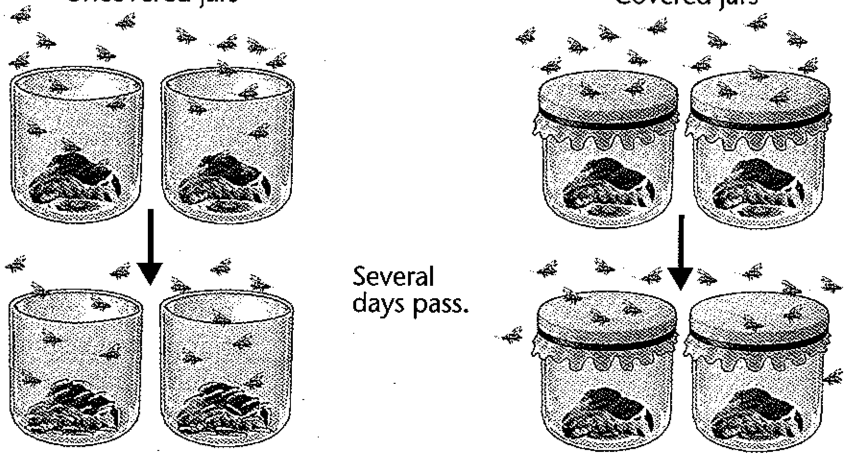
**OBSERVATIONS:** Flies land on meat that is left uncovered. Later, maggots appear on the meat.

**HYPOTHESIS:** Flies produce maggots.

**PROCEDURE**

Uncovered jars

Covered jars



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

Several days pass.

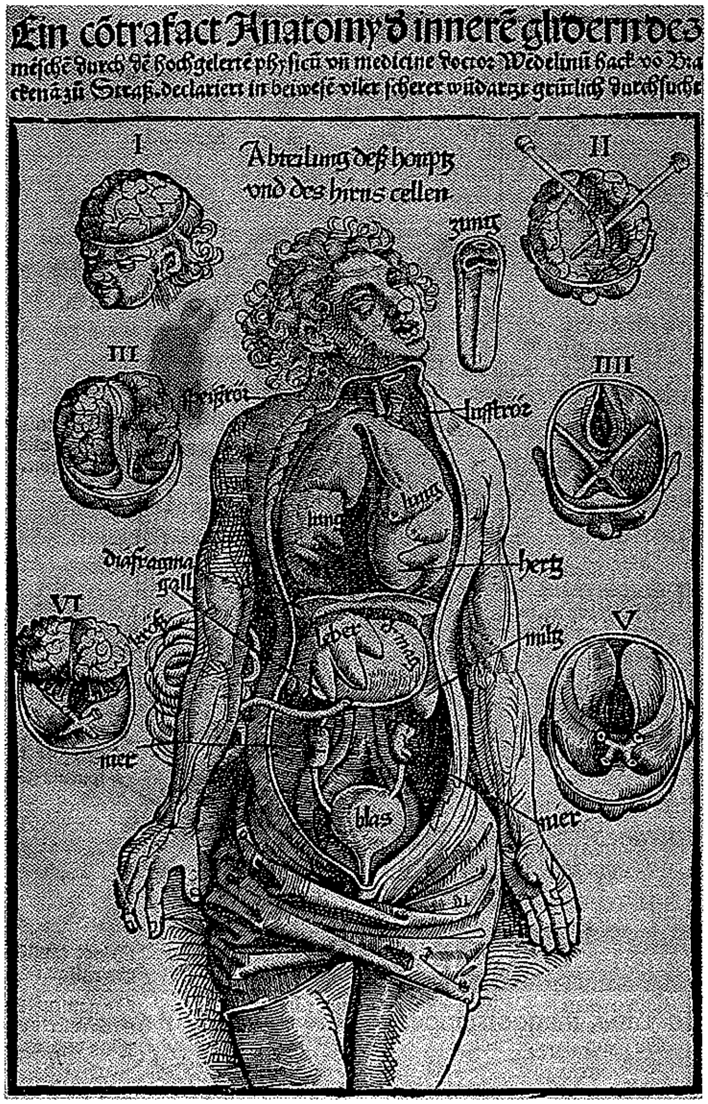
**Manipulated Variable:** gauze covering that keeps flies away from meat

**Responding Variable:** whether maggots appear

Maggots appear

No maggots appear

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




▲ **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.

## Publishing and 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.

# 1–3 Studying Life

## *Guide for Reading*

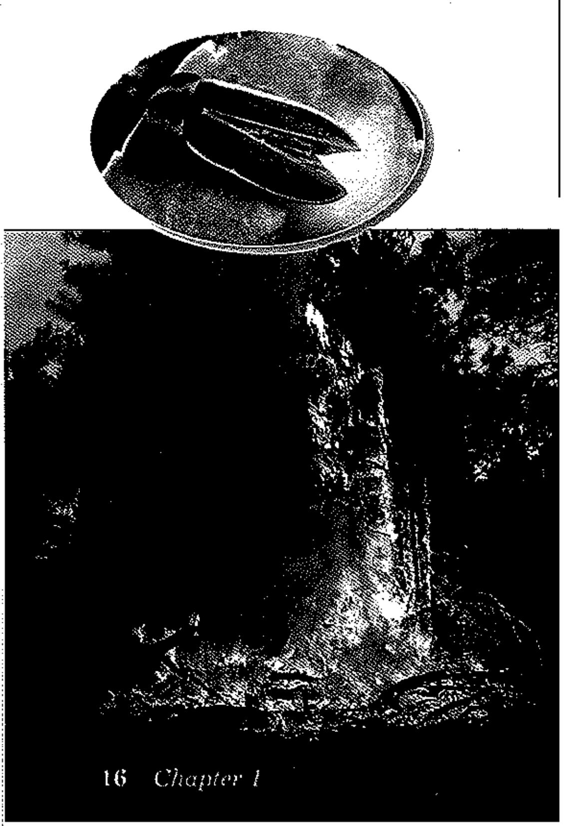
**Key Concepts**

- What are some characteristics of living things?
- How can life be studied at different levels?

**Vocabulary**

biology
cell
sexual reproduction
asexual reproduction
metabolism
stimulus
homeostasis
evolution

**Reading Strategy: Summarizing** As you read, make a list of the properties of living things. Write one sentence describing each property.



Beneath the sparkling waves near a South Pacific island, divers carry cameras and underwater notepads as they crisscross a coral reef. Outside an Antarctic research station, a lone figure searches the ice around her for signs of life. In a high-security facility in Atlanta, a man dressed like an astronaut passes through a double airlock into a sterile laboratory. Sweltering in the heat and humidity of sub-Saharan Africa, volunteers collect blood samples from women and children with AIDS. What do these people have in common? They are biologists.

The word *biology* means the study of life. (The Greek word *bios* means "life," and *-logy* means "study of.") **Biology** is the science that seeks to understand the living world. A biologist is someone who uses scientific methods to study living things. The work of biologists can be quite varied, because organisms are complex and vary so greatly.

## Characteristics of Living Things

Are the firefly and the fire in **Figure 1–14** alive? They are both giving off energy. Describing what makes something alive is not easy. No single characteristic is enough to describe a living thing. Also, some nonliving things share one or more traits with living things. Mechanical toys, automobiles, and clouds move around, for example, whereas mushrooms and trees live their lives in one spot. Other things, such as viruses, exist at the border between organisms and nonliving things. (You'll read more about viruses in Chapter 19.)

Despite these difficulties, it is possible to describe what most living things have in common. **Living things share the following characteristics:**

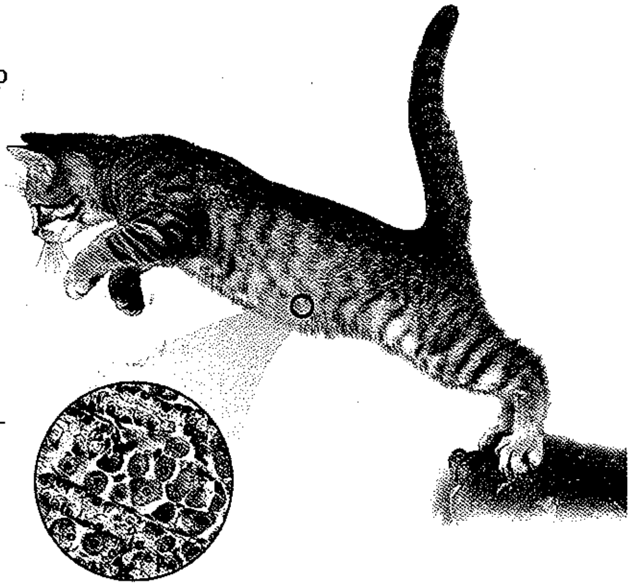
- **Living things are made up of units called cells.**
- **Living things reproduce.**
- **Living things are based on a universal genetic code.**
- **Living things grow and develop.**
- **Living things obtain and use materials and energy.**
- **Living things respond to their environment.**
- **Living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

**Figure 1–14** A Colorado firefly beetle (top) has all of the characteristics of living things. Even though fire (bottom) uses materials and can grow as living things do, fire is not alive because it does not have other characteristics of living things. **Applying Concepts** *What characteristics of living things are missing from a fire?*

**Made Up of Cells** Living things, or organisms, are made up of small, self-contained units called cells. A **cell** is a collection of living matter enclosed by a barrier that separates the cell from its surroundings. Cells are the smallest units of an organism that can be considered alive. Cells can grow, respond to their surroundings, and reproduce. Despite their small size, cells are complex and highly organized.

Many living things consist of only a single cell and are therefore called unicellular organisms. (The Latin prefix *uni-* means "one," so *unicellular* means "single-celled.") Many of the microorganisms involved in Spallanzani's and Pasteur's experiments were unicellular organisms.

The organisms you are most familiar with—for example, animals and plants—are multicellular. You can see one type of multicellular organism in **Figure 1–15.** (The Latin prefix *multi-* means "many." Thus, *multicellular* means "many-celled.") Multicellular organisms contain hundreds, thousands, or even trillions of cells. The cells in these organisms are often remarkably diverse, existing in a variety of sizes and shapes. In some multicellular organisms, each type of cell is specialized to perform a different function. The human body alone is made up of at least 85 different cell types. You will learn more about cells in Chapter 7.



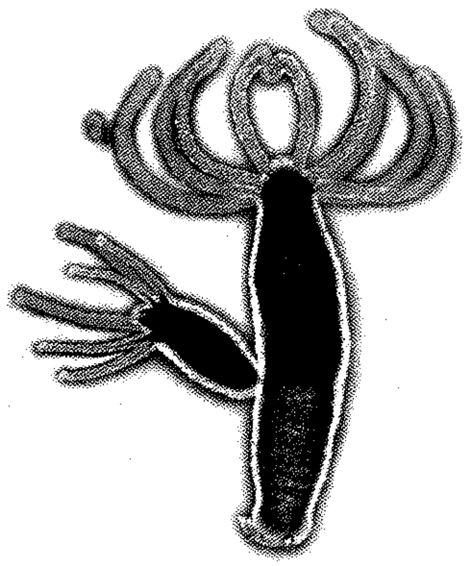
▲ **Figure 1–15** **Living things are made of cells.** Cats and most other familiar organisms are made of many cells. The inset shows cells from a cat's stomach (magnification: 500×).

**Reproduction** All organisms produce new organisms through a process called reproduction. There are two basic kinds of reproduction: sexual and asexual. The vast majority of multicellular organisms—from maple trees to birds and humans—reproduce sexually. In **sexual reproduction,** two cells from different parents unite to produce the first cell of the new organism. In **asexual reproduction,** the new organism has a single parent. In some forms of asexual reproduction, a single-celled organism divides in half to form two new organisms. In the type of asexual reproduction shown in **Figure 1–16,** a portion of an organism splits off to form a new organism.

CHECKPOINT *What is sexual reproduction?*

**Based on a Genetic Code** Offspring usually resemble their parents. With asexual reproduction, offspring and their parents have the same traits. With sexual reproduction, offspring differ from their parents in some ways. However, there are limits to these differences. Flies produce flies, dogs produce dogs, and seeds from maple trees produce maple trees.

Explaining how organisms inherit traits is one of the greatest achievements of modern biology. Biologists now know that the directions for inheritance are carried by a molecule called deoxyribonucleic acid, or DNA. This genetic code, with a few minor variations, determines the inherited traits of every organism on Earth. You will learn how this is possible in Unit 4.



▲ **Figure 1–16** **All living things reproduce.** Here, one hydra is being formed from another through a type of asexual reproduction called budding. Shortly, the new organism will break away from the parent and live independently.

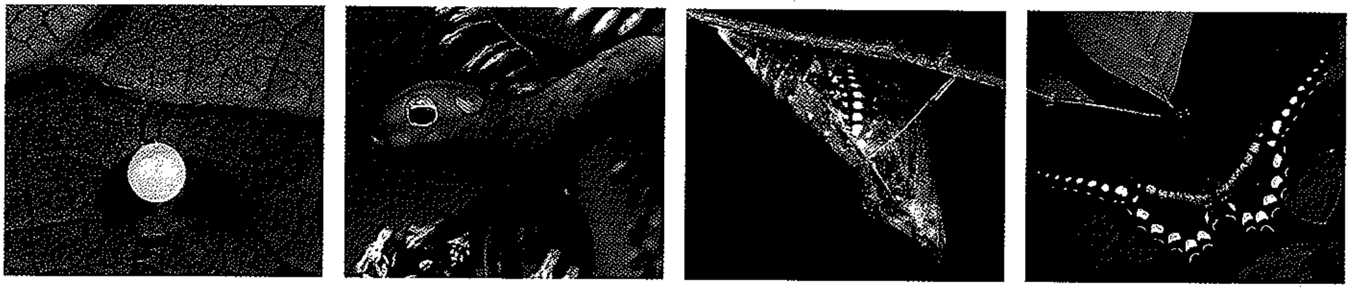


**Figure 1–17 All living things grow and develop.** These photographs show how a spicebush swallowtail butterfly develops from an egg into a caterpillar (larva), a pupa, and, finally, an adult butterfly.

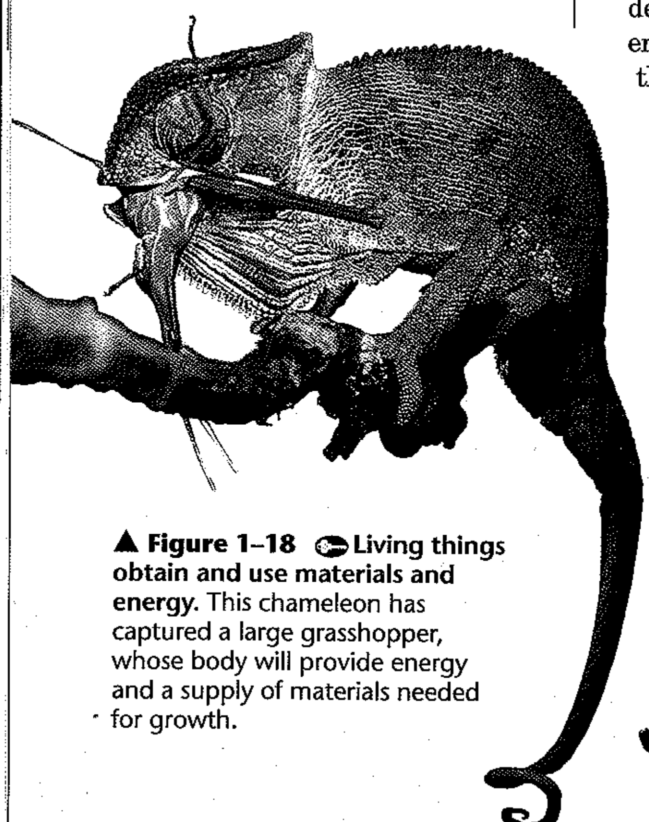
**Growth and Development** All living things grow during at least part of their lives. For some single-celled organisms, such as bacteria, growth is mostly a simple increase in size. Multicellular organisms, however, typically go through a process called development. During development, a single fertilized egg cell divides again and again to produce the many cells of mature organisms. As those cells divide, they change in shape and structure to form cells such as liver cells, brain cells, and muscle cells. This process is called differentiation, because it forms cells that look different from one another and perform different functions.

For many organisms, development includes periods of rapid and dramatic change, as shown in **Figure 1–17.** In fact, although you will not sprout wings, your body is currently experiencing one of the most intense spurts of growth and development of your entire life!

**Need for Materials and Energy** Think of what an organism needs as it grows and develops. Just as a building grows taller because workers use energy to assemble new materials, an organism uses energy and a constant supply of materials to grow, develop, and reproduce. Organisms also need materials and energy just to stay alive. The combination of chemical reactions through which an organism builds up or breaks down materials as it carries out its life processes is called **metabolism.**

All organisms take in selected materials that they need from their surroundings, or environment, but the way they obtain energy varies. Plants, some bacteria, and most algae obtain their energy directly from sunlight. Through a process called photosynthesis, these organisms convert light into a form of energy that is stored in certain molecules. That stored energy is ready to be used when needed.

Most other organisms rely on the energy stored during photosynthesis. Some organisms, such as grasshoppers and sheep, obtain their energy by eating plants and other photosynthesizing organisms. Other organisms, such as birds and wolves, get energy by eating the grasshoppers or sheep. The chameleon in **Figure 1–18** gets the materials it needs by eating insects and other small animals. And some organisms, called decomposers, obtain energy from the remains of organisms that have died.

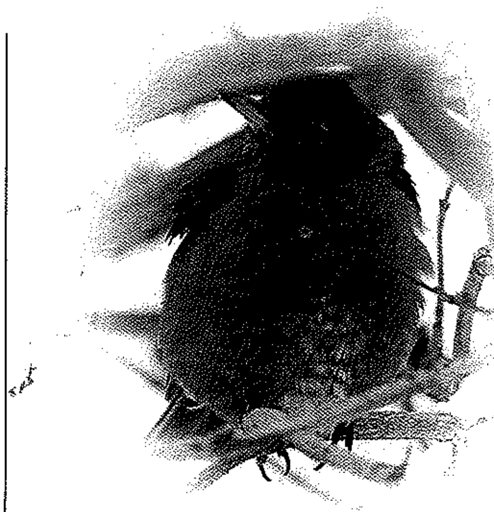


▲ **Figure 1–18 Living things obtain and use materials and energy.** This chameleon has captured a large grasshopper, whose body will provide energy and a supply of materials needed for growth.

CHECKPOINT *What is metabolism?*

**Response to the Environment** Organisms detect and respond to stimuli from their environment. A **stimulus** is a signal to which an organism responds. External stimuli, which come from the environment outside an organism, include factors such as light and temperature. For example, when there is sufficient water and the ground is warm enough, a plant seed responds by germinating. The roots respond to gravity and grow down into the soil. The new leaves and stems grow toward light. In contrast, internal stimuli come from within an organism. The level of the sugar glucose in your blood is an example of an internal stimulus. If this level becomes low enough, your body responds by making you feel hungry.

**Maintaining Internal Balance** Even though conditions in the external environment may vary widely, most organisms must keep internal conditions, such as temperature and water content, fairly constant to survive. The process by which they do this is called **homeostasis** (hoh-mee-oh-STAY-sis). Homeostasis often involves internal feedback mechanisms that work in much the same way as a thermostat. Just as a thermostat in your home turns on the heat when room temperature drops below a certain point, you have an internal "thermostat" that makes your body shiver if your internal temperature drops too low. The muscle action involved in shivering produces heat, thus warming your body. In contrast, if you get too hot, your biological thermostat turns on "air conditioning" by causing you to sweat. Sweating helps to remove excess heat from your skin. When birds get cold, they hunch down and adjust their feathers to provide maximum insulation, as shown in **Figure 1–19.** Often internal stimuli help maintain homeostasis. For example, when your body needs more water to maintain homeostasis, internal stimuli make you feel thirsty.



▲ **Figure 1–19** **Living things maintain an internal stability.** Despite the cold temperatures of this robin's environment, its body temperature remains fairly constant, partly because its feathers provide a layer of insulation and partly because of the body heat it produces.

## Quick Lab

### What are the characteristics of living things?

**Materials** hand lens, unknown objects (dry), same objects soaked in water

**Procedure**

1. Examine the dry unknown object your teacher provides. Record your observations.
2. **Predicting** In step 3, you will observe the same kind of object after it has been soaked in water. Write a prediction describing what you expect to see.
3. Examine one of the objects that has been soaking in water for a period of time. Record your observations. Wash your hands when you have finished.

**Analyze and Conclude**

1. **Evaluating** Was the prediction you made in step 2 correct? Explain your answer.
2. **Inferring** Were the objects you observed in step 1 living or nonliving? Were the objects you observed in step 3 living or nonliving? Use the observations you made as supporting evidence for your answers.
3. **Formulating Hypotheses** Suggest one or more ways to explain the differences between the dry and wet objects.

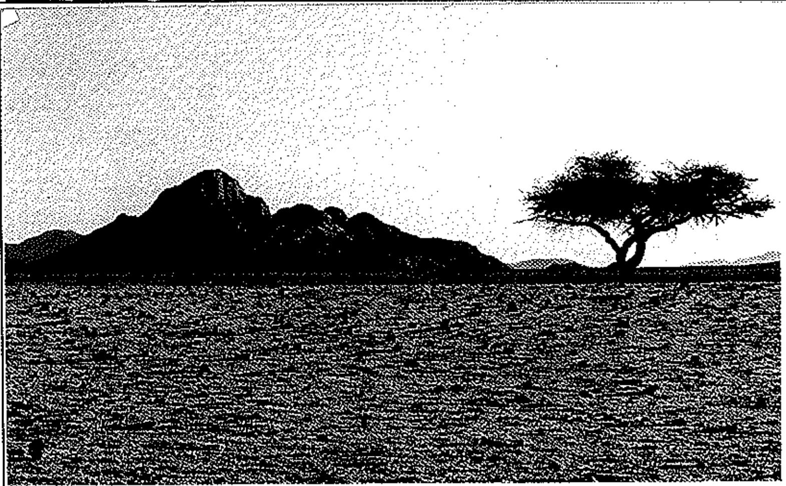


**Figure 1–20** **Taken as a group, all living things change over time.** If you suddenly moved most plants to this Namibian desert (left), they would be killed by the heat and lack of water. But a few types of plants have become adapted to these hot and dry conditions, surviving periods of drought to grow and flower after a rainfall (right).

**Evolution** Although individual organisms experience many changes during their lives, the basic traits they inherited from their parents usually do not change. As a group, however, any given kind of organism can evolve, or change over time.

Over a few generations, the changes in a group may not seem significant. But over hundreds of thousands or even millions of years, the changes can be dramatic. The ability of certain plants, such as those in **Figure 1–20,** to survive periods without water is one example. Another example concerns fishes. Scientists study deposits containing the remains of animals that lived long ago to learn about the evolution of organisms. From the study of very early deposits, scientists know that at one time there were no fishes in Earth's waters. Yet, in more recent deposits, the remains of fishes and other animals with backbones are abundant. The ability of a group of organisms to change over time is invaluable for survival in a world that is always changing. You will read about the processes of **evolution** in Unit 5.

## Branches of Biology

Living things come in an astonishing variety of shapes, sizes, and habits. Living systems also range in size from groups of molecules that make up structures inside cells to the collections of organisms that make up the biosphere. No single biologist could study all this diversity, so biology is divided into different fields. Some fields are based on the types of organisms being studied. Zoologists study animals. Botanists study plants. Other fields study life from a particular perspective. For example, paleontologists study ancient life.

Some fields focus on the study of living systems at different levels of organization, as shown in **Figure 1–21.** **Some of the levels at which life can be studied include molecules, cells, organisms, populations of a single kind of organism, communities of different organisms in an area, and the biosphere. At all these levels, smaller living systems are found within larger systems.** Molecular biologists and cell biologists study some of the smallest living systems. Population biologists and ecologists study some of the largest systems in nature. Studies at all these levels make important contributions to the quality of human life.

## Levels of Organization

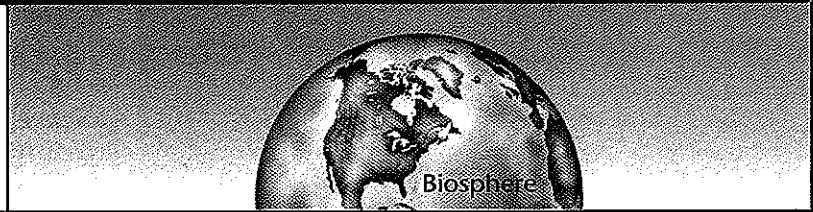
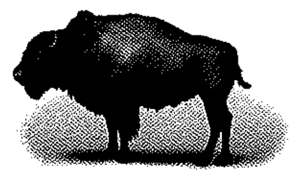
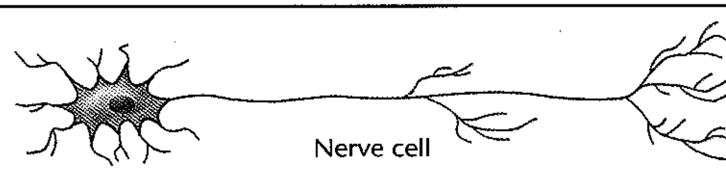
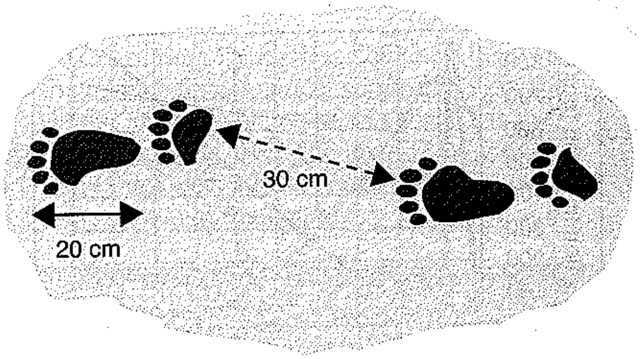
| | | |
|---|---|---|
| **Biosphere** | The part of Earth that contains all ecosystems |  Biosphere |
| **Ecosystem** | Community and its nonliving surroundings |  Hawk, snake, bison, prairie dog, grass, stream, rocks, air |
| **Community** | Populations that live together in a defined area |  Hawk, snake, bison, prairie dog, grass |
| **Population** | Group of organisms of one type that live in the same area |  Bison herd |
| **Organism** | Individual living thing |  Bison |
| **Groups of Cells** | Tissues, organs, and organ systems |  Nervous tissue, Brain, Nervous system |
| **Cells** | Smallest functional unit of life |  Nerve cell |
| **Molecules** | Groups of atoms; smallest unit of most chemical compounds |  Water, DNA |

**Figure 1–21 Living things may be studied on many different levels.** The largest and most complex level is the biosphere. The smallest level is the molecules that make up living things.

# Basic Process Skills

During a biology course, you often carry out short lab activities as well as lengthier experiments. Here are some skills that you will use.




## Observing

In every science activity, you make a variety of observations. Observing is using one or more of the five senses to gather information. Many observations involve the senses of sight, hearing, touch, and smell. On rare occasions in a lab—but only when explicitly directed by your teacher—you may use the sense of taste to make an observation.

Sometimes you will use tools that increase the power of your senses or make observations more precise. For example, hand lenses and microscopes enable you to see things in greater detail. Rulers, balances, and thermometers help you measure key variables. Besides expanding the senses or making observations more accurate, tools may help eliminate personal opinions or preferences.

In science, it is customary to record your observations at the time they are made, usually by writing or drawing in a notebook. You may also make records by using computers, cameras, videotapes, and other tools. As a rule, scientists keep complete accounts of their observations, often using tables to organize their observations.

## Inferring

In science, as in daily life, observations are usually followed by inferences. Inferring is interpreting an observation or statement based on prior knowledge.

**Comparing Observations and Inferences**

| Sample Observations | Sample Inferences |
|---|---|
| The footprints in the soil each have five toes. | An animal made the footprints. |
| The larger footprints are about 20 cm long. | A bear made the footprints. |
| The space between each pair of footprints is about 30 cm. | The animal was walking, not running. |

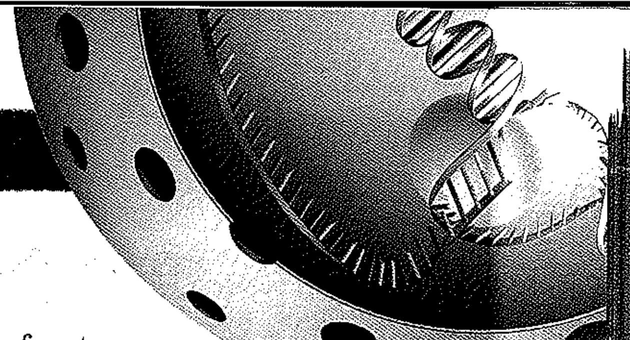
For example, suppose you're on a mountain hike and you see footprints in wet soil. Based on their size and shape, you might infer that a large mammal had passed by. In making that inference, you would use your knowledge about the shape of animals' feet. Someone who knew much more about mammals might infer that a bear left the footprints. You can compare examples of observations and inferences in the table above.

Notice that an inference is an act of reasoning, not a fact. An inference may be logical but not true. It is often necessary to gather further information before you can be confident that an inference is correct. For scientists, that information may come from further observations or from research done by others.

As you study biology, you may make different types of inferences. For example, you may generalize about all cases based on information about some cases: *All the plant roots I've observed grow downward, so I infer that all roots grow downward.* You may determine that one factor or event was caused by another factor or event: *The bacteria died after I applied bleach, so I infer that bleach kills bacteria.* Predictions may be another type of inference.

## Predicting

People often make predictions, but their statements about the future could be either guesses or inferences. In science, a prediction is an inference about a future event based on evidence, experience, or knowledge. For example, you can say, *On the first day next month, it will be sunny.* If your statement is based on evidence of weather patterns in the area, then the prediction is scientific. If the statement was made without considering any evidence, it's just a guess.



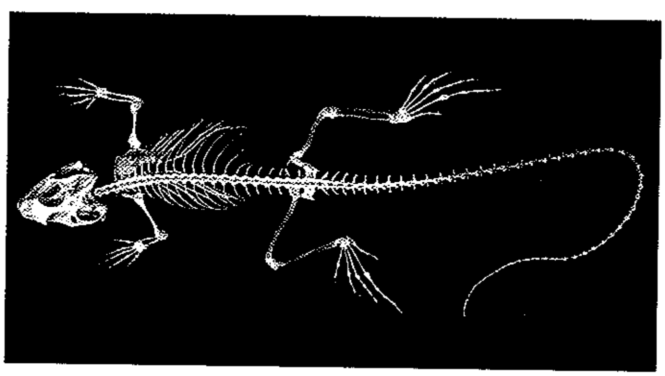
Predictions play a major role in science because they provide a way to test ideas. If scientists understand an event or the properties of a particular object, they should be able to make accurate predictions about that event or object. Some predictions can be tested simply by making observations. At other times, carefully designed experiments are needed. You'll read more about the relationship between predictions and experiments on the next two pages.

## Classifying

If you have ever heard people debate whether a tomato is a fruit or a vegetable, you've heard an argument about classification. Classifying is the process of grouping items that are alike according to some organizing idea or system. Classifying occurs in every branch of science, but it is especially important in biology because living things are so numerous and diverse.

You may have the chance to practice classifying in different ways. Sometimes you will place objects into groups using an established system. At other times, you may create a system of your own by examining a variety of objects and identifying their properties.

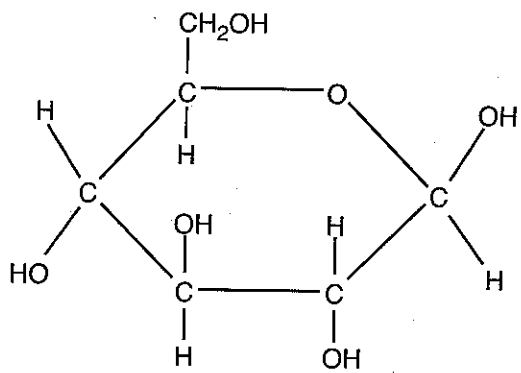
Classification can have different purposes. Sometimes it's done just to keep things organized, for example, to make lab supplies easy to find. More likely, though, classification helps scientists understand living things better and discover relationships among them. For example, biologists classify certain animal parts as bone or muscle and investigate how they work together. One way biologists determine how groups of vertebrates are related is to compare their bones.



## Using Models

Some cities refuse to approve any new buildings that could cast shadows on a popular park. As architects plan buildings in such locations, they use models that can show where a proposed building's shadow will fall at any time of day at any season of the year. A model is a mental or physical representation of an object, process, or event. In science, models are usually made to help people understand natural objects and processes.

**Model of a Glucose Molecule**



Models can be varied. Mental models, such as mathematical equations, can represent some kinds of ideas or processes. For example, the equation for the surface area of a sphere can model the surface of Earth, enabling scientists to determine its size. Physical models can be made of a huge variety of materials; they can be two-dimensional (flat) or three-dimensional (having depth). In biology, a drawing of a molecule or a cell is a typical two-dimensional model. Common three-dimensional models include a representation of a DNA molecule and a plastic skeleton of an animal.

Physical models can also be made "to scale," which means they are in proportion to the actual object. Something very large, such as an area of land being studied, can be shown at 1/100 of its actual size. A tiny organism can be shown at 100 times its size.

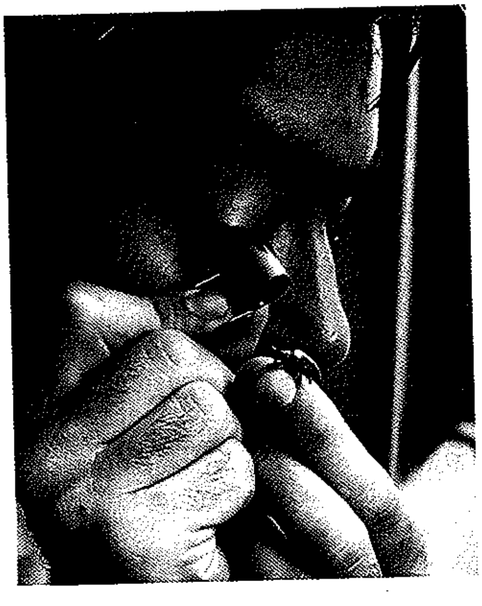
# Conducting an Experiment

A science experiment is a procedure designed to test a prediction. Some types of experiments are fairly simple to design. Others may require ingenious problem solving.

## Starting With Questions or Problems

A gardener collected seeds from a favorite plant at the end of the summer, stored them indoors for the winter, then planted them the following spring. None of the stored seeds developed into plants, yet uncollected seeds from the original plant germinated in the normal way. The gardener wondered: *Why didn't the collected seeds germinate?*

An experiment may have its beginning when someone asks a specific question or wants to solve a particular problem. Sometimes the original question leads directly to an experiment, but often researchers must restate the problem before they can design an appropriate experiment. The gardener's question about the seeds, for example, is too broad to be tested by an experiment, because there are so many possible answers. To narrow the topic, the gardener might think about related questions: *Were the seeds I collected different from the uncollected seeds? Did I try to germinate them in poor soil or with insufficient light or water? Did storing the seeds indoors ruin them in some way?*



## Developing a Hypothesis

In science, a question about an object or event is answered by developing a possible explanation called a **hypothesis.** The hypothesis may be developed after long thought and research, or it may come to a scientist "in a flash." How a hypothesis is formed doesn't matter; it can be useful as long as it leads to predictions that can be tested.

The gardener decided to focus on the fact that the nongerminating seeds were stored in the warm conditions of a heated house. That led the person to propose this hypothesis: *Seeds require a period of low temperatures in order to germinate.* The next step is to make a prediction based on the hypothesis, for example: *If seeds are stored indoors in cold conditions, they will germinate in the same way as seeds left outdoors during the winter.* Notice that the prediction suggests the basic idea for an experiment.

## Designing an Experiment

A carefully designed experiment can test a prediction in a reliable way, ruling out other possible explanations. As scientists plan their experimental procedures, they pay particular attention to the factors that must be controlled.

The gardener decided to study three groups of seeds: (1) some that would be left outdoors throughout the winter, (2) some that would be brought indoors and kept at room temperature, and (3) some that would be brought indoors and kept cold.

## Controlling Variables

As researchers design an experiment, they identify the **variables,** factors that can change. Some common variables include mass, volume, time, temperature, light, and the presence or absence of specific materials. An experiment involves three categories of variables. The factor that scientists purposely change is called the **manipulated variable.** A manipulated variable is also known as an **independent variable**. The factor that may change because of the manipulated variable and that scientists want to observe is called the **responding variable.** A responding variable is also known as a **dependent variable.** Factors that scientists purposely keep the same are called **controlled variables.** Controlling variables enables researchers to conclude that the changes in the responding variable are due exclusively to changes in the manipulated variable.

### What Is a Control Group?

When you read about certain experiments, you may come across references to a control group (or "a control") and the experimental groups. All the groups in an experiment are treated exactly the same except for the manipulated variable. In the experimental group, the manipulated variable is being changed. The control group is used as a standard of comparison. It may consist of objects that are not changed in any way or objects that are being treated in the usual way. For example, in the gardener's experiment, the seeds left outdoors would be the control group, because they reveal what happens under natural conditions.

For the gardener, the manipulated variable is whether the seeds were exposed to cold conditions. The responding variable is whether or not the seeds germinate. Among the variables that must be controlled are whether the seeds remain dry during storage, when the seeds are planted, the amount of water the seeds receive, and the type of soil used.

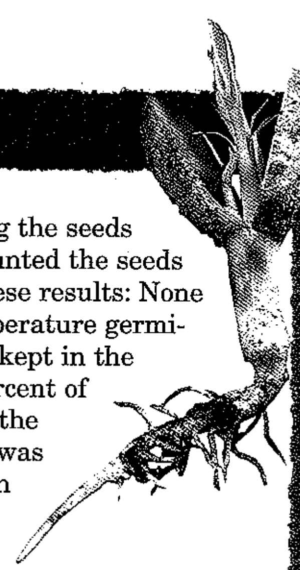
## Forming Operational Definitions

In an experiment, it is often necessary to define one or more variables explicitly so that any researcher could measure or control the variable in exactly the same way. An **operational definition** describes how a particular variable is to be measured or how a term is to be defined. ("Operational" means "describing what to do.")

The gardener, for example, had to decide exactly what the indoor "cold" conditions of the experiment would involve. Since winter temperatures often fell below freezing, the gardener decided that "cold" would mean keeping the seeds in a freezer.

## Interpreting Data

The observations and measurements that are made in an experiment are called **data.** Scientists usually record data in an orderly way. When an experiment is finished, the researcher analyzes the data for trends or patterns, often by doing calculations or making graphs, to determine whether the results support the hypothesis.



For example, after planting the seeds in the spring, the gardener counted the seeds that germinated and found these results: None of the seeds kept at room temperature germinated, 80 percent of the seeds kept in the freezer germinated, and 85 percent of the seeds left outdoors during the winter germinated. The trend was clear: The gardener's prediction appeared to be correct.

To be sure that the results of an experiment are correct, scientists review their data critically, looking for possible sources of error. Here, "error" refers to differences between the observed results and the true values. Experimental error can result from human mistakes or problems with equipment. It can also occur when the small group of objects studied does not accurately represent the whole group. For example, if some of the gardener's seeds had been exposed to a herbicide, the data might not reflect the true seed germination pattern.

## Drawing Conclusions

If researchers are confident that their data is reliable, they make a final statement summarizing their results. That statement—called the conclusion of the experiment—indicates whether the data support or refute the hypothesis. The gardener's conclusion was: *Some seeds must undergo a period of freezing in order to germinate.* A conclusion is considered valid if it is a logical interpretation of reliable data.

## Following Up an Experiment

When an experiment has been completed, one or more events often follow. Researchers may repeat the experiment to verify the results. They may publish the experiment so that others can evaluate and replicate their procedures. They may compare their conclusion with the discoveries made by other scientists. And they may raise new questions that lead to new experiments. For example, *Are the spores of fungi affected by temperature as these seeds were?*

Researching other discoveries about seeds would show that some other types of plants in temperate zones require periods of freezing before they germinate. Biologists infer that this pattern makes it less likely the seeds will germinate before winter, thus increasing the chances that the young plants will survive.