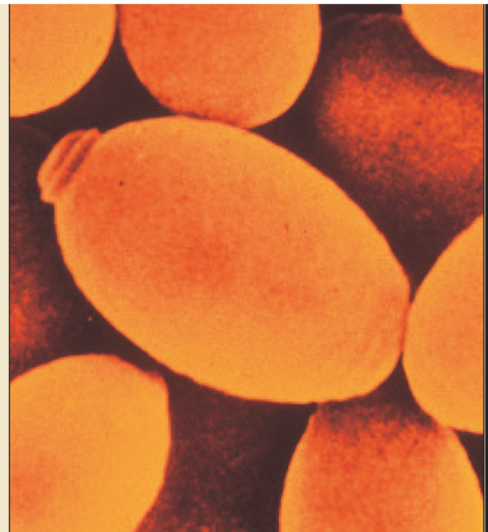
1 What Is Biology?



CHAPTER 1

PART ONE Introduction

Chapter Outline

It is often helpful when learning new material to have the goals clearly stated before that material is presented. It is also helpful to have some idea why the material will be relevant. This information can provide a framework for organization as well as serve as a guide to identify the most important facts. The following table will help you identify the key topics of this chapter as well as the significance of mastering those topics.

Key Concepts	Applications
Understand the process of science as well as differentiate between science and nonscience.	• Know if information is the result of scientific investigation. • Explain when "scientific claims" are really scientific. • Recognize that some claims are pseudoscientific and are designed to mislead.
Understand that many advances in the quality of life are the result of biological discoveries.	• Give examples of how biological discoveries have improved your life. • Recognize how science is relevant for you.
Differentiate between applied and theoretical science.	• Describe the kinds of problems biologists have to deal with now and in the future.
Recognize that science has limitations.	• Give examples of problems caused by unwise use of biological information. • Identify questions that science is not able to answer.
Know the characteristics used to differentiate between living and nonliving things.	• Correctly distinguish between living and nonliving things.

1.1 The Significance of Biology in Your Life

Many college students question the need for science courses such as biology in their curriculum, especially when their course of study is not science related. However, it is becoming increasingly important that all citizens be able to recognize the power and limitations of science, understand how scientists think, and appreciate how the actions of societies change the world in which we and other organisms live. Consider how your future will be influenced by how the following questions are ultimately answered:

- Does electromagnetic radiation from electric power lines, computer monitors, cell phones, or microwave ovens affect living things?
- Is DNA testing reliable enough to be admitted as evidence in court cases?
- Is there a pill that can be used to control a person's weight?
- Can physicians and scientists manipulate our genes in order to control certain disease conditions we have inherited?
- Will the thinning of the ozone layer of the upper atmosphere result in increased incidence of skin cancer?
- Will a vaccine for AIDS be developed in the next 10 years?
- Will new, inexpensive, socially acceptable methods of birth control be developed that can slow world population growth?
- Are human activities really causing the world to get warmer?
- How does extinction of a species change the ecological situation where it once lived?

As an informed citizen in a democracy, you can have a great deal to say about how these problems are analyzed and what actions provide appropriate solutions. In a democracy it is assumed that the public has gathered enough information to make intelligent decisions (figure 1.1). This is why an understanding of the nature of science and fundamental biological concepts is so important for any person, regardless of his or her vocation. *Concepts in Biology* was written with this philosophy in mind. The concepts covered in this book are core concepts selected to help you become more aware of how biology influences nearly every aspect of your life.

Most of the important questions of today can be considered from philosophical, social, and scientific standpoints. None of these approaches individually presents a solution to most problems. For example, it is a fact that the human population of the world is growing very rapidly. Philosophically, we may all agree that the rate of population growth should be slowed. Science can provide information about why populations grow and which actions will be the most effective in slowing population growth. Science can also develop methods of conception control that would limit a person's ability to reproduce. Killing infants and forced sterilization are both methods that have been tried in some parts of the world within the past century. However, most would contend that these "solutions" are philosophically or socially unacceptable. Science can provide information about the reproductive process and how it can be controlled, but society must answer the more fundamental social and philosophical questions about reproductive rights and the morality of controls. It is important to recognize that science has a role to play but that it does not have the answers to all our problems.

Figure 1.1

Biology in Everyday Life
These news headlines reflect a few of the biologically based issues that face us every day. Although articles such as these seldom propose solutions, they do inform the general public so that people can begin to explore possibilities and make intelligent decisions leading to solutions.

1.2 Science and the Scientific Method

You already know that biology is a scientific discipline and that it has something to do with living things such as microorganisms, plants, and animals. Most textbooks define **biology** as the science that deals with life. This basic definition seems clear until you begin to think about what the words *science* and *life* mean.

The word *science* is a noun derived from a Latin term (*scientia*) meaning *knowledge* or *knowing*. Humans have accumulated a vast amount of "knowledge" using a variety of methods, some by scientific methods and some by other methods.

Science is distinguished from other fields of study by *how* knowledge is acquired, rather than by the act of accumulating facts. **Science** is actually a process used to solve problems or develop an understanding of natural events that involves testing possible answers. The process has become known as the *scientific method*. The **scientific method** is a way of gaining information (facts) about the world by forming possible solutions to questions followed by rigorous testing to determine if the proposed solutions are valid (*valid* = meaningful, convincing, sound, satisfactory, confirmed by others).

When using the scientific method, scientists make several fundamental assumptions. There is a presumption that:

1. There are specific causes for events observed in the natural world,
2. That the causes can be identified,
3. That there are general rules or patterns that can be used to describe what happens in nature,
4. That an event that occurs repeatedly probably has the same cause,
5. That what one person perceives can be perceived by others, and
6. That the same fundamental rules of nature apply regardless of where and when they occur.

For example, we have all observed lightning associated with thunderstorms. According to the assumptions that have just been stated, we should expect that there is an explanation that would explain all cases of lightning regardless of where or when they occur and that all people could make the same observations. We know from scientific observations and experiments that lightning is caused by a difference in electrical charge, that the behavior of lightning follows general rules that are the same as that seen with static electricity, and that all lightning that has been measured has the same cause wherever and whenever it occurred.

Scientists are involved in distinguishing between situations that are merely correlated (happen together) and those that are correlated and show *cause-and-effect relationships*. When an event occurs as a direct result of a previous event, a cause-and-effect relationship exists. Many events are correlated, but not all correlations show a cause-and-effect relationship. For example, lightning and thunder are correlated and have a cause-and-effect relationship. However, the relationship between autumn and trees dropping their leaves is more difficult to sort out. Because autumn brings colder temperatures many people assume that the cold temperature is the cause of the leaves turning color and falling. The two events are correlated. However there is no cause-and-effect relationship. The cause of the change in trees is the shortening of days that occurs in the autumn. Experiments have shown that artificially shortening the length of days in a greenhouse will cause the trees to drop their leaves even though there is no change in temperature. Knowing that a cause-and-effect relationship exists enables us to make predictions about what will happen should that same set of circumstances occur in the future.

This approach can be used by scientists to solve particular practical problems, such as how to improve milk production in cows or to advance understanding of important concepts such as evolution that may have little immediate practical value. Yet an understanding of the process of evolution is important in understanding genetic engineering, the causes of extinction, or human physiology—all of which have practical applications. The scientific method requires a systematic search for information and a continual checking and rechecking to see if previous ideas are still supported by new information. If the new evidence is not supportive, scientists discard or change their original ideas. Scientific ideas undergo constant reevaluation, criticism, and modification.

The scientific method involves several important identifiable components, including careful observation, the construction and testing of hypotheses, an openness to new information and ideas, and a willingness to submit one's ideas to the scrutiny of others. However, it is not an inflexible series of steps that must be followed in a specific order. Figure 1.2 shows how these steps may be linked and table 1.1 gives an example of how scientific investigation proceeds from an initial question to the development of theories and laws.

Observation

Scientific inquiry often begins with an observation that an event has occurred repeatedly. An **observation** occurs when we use our senses (smell, sight, hearing, taste, touch) or an extension of our senses (microscope, tape recorder, X-ray machine, thermometer) to record an event. Observation is more than a casual awareness. You may hear a sound or see an image without really observing it. Do you know what music was being played in the shopping mall? You certainly heard it but if you are unable to tell someone else what it was, you didn't "observe" it. If you had prepared yourself to observe the music being played, you would be able to identify it. When scientists talk about their observations, they are referring to careful, thoughtful recognition of an event—not just casual notice. Scientists train themselves to improve their observational skills since careful observation is important in all parts of the scientific method.

The information gained by direct observation of the event is called **empirical evidence** (*empiric* = based on experience; from the Greek *empirikos* = experience). Empirical evidence is capable of being verified or disproved by further observation. If the event occurs only once or cannot be repeated in an artificial situation, it is impossible to use the

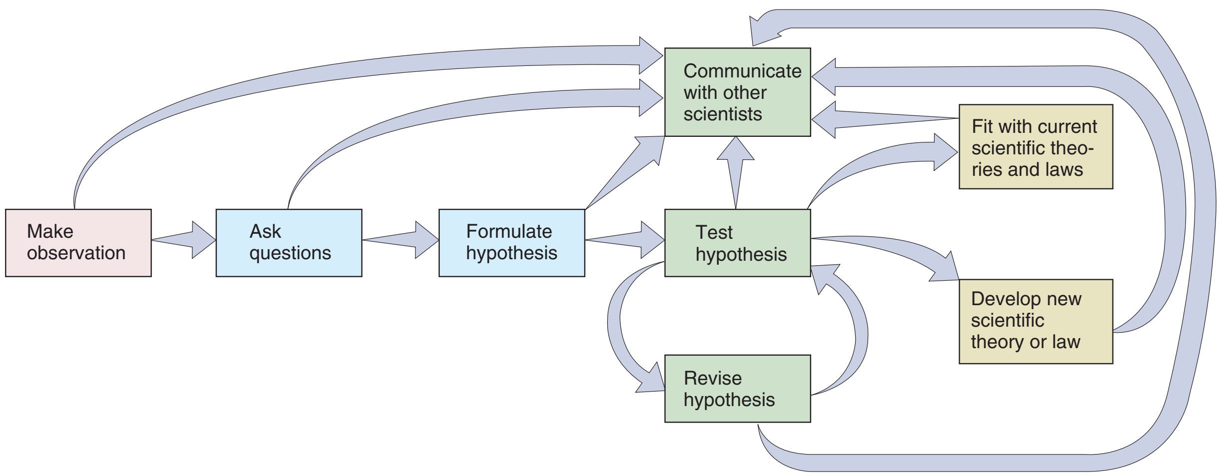


Figure 1.2

The Scientific Method

The scientific method is a way of thinking that involves making hypotheses about observations and testing the validity of the hypotheses. When hypotheses are disproved, they can be revised and tested in their new form. Throughout the scientific process, people communicate about their ideas. Theories and laws develop as a result of people recognizing broad areas of agreement about how the world works. Current laws and theories help people formulate their approaches to scientific questions.

scientific method to gain further information about the event and explain it.

Questioning and Exploration

As scientists gain more empirical evidence about an event they begin to develop *questions* about it. How does this happen? What causes it to occur? When will it take place again? Can I control the event to my benefit? The formation of the questions is not as simple as it might seem because the way the questions are asked will determine how you go about answering them. A question that is too broad or too complex may be impossible to answer; therefore a great deal of effort is put into asking the question in the right way. In some situations, this can be the most time-consuming part of the scientific method; asking the right question is critical to how you look for answers.

Let's say, for example, that you observed a cat catch, kill, and eat a mouse. You could ask several kinds of questions:

1a. Does the cat like the taste of the mouse?
1b. If given a choice between mice and canned cat food, which would a cat choose?
2a. What motivates a cat to hunt?
2b. Do cats hunt only when they are hungry?

Obviously, 1b and 2b are much easier to answer than 1a and 2a even though the two sets of questions are attempting to obtain similar information.

Once a decision has been made about what question to ask, scientists *explore other sources of knowledge* to gain more information. Perhaps the question has already been answered by someone else or several possible answers have already been rejected. Knowing what others have already done allows one to save time and energy. This process usually involves reading appropriate science publications, exploring information on the Internet, or contacting fellow scientists interested in the same field of study. Even if the particular question has not been answered already, scientific literature and other scientists can provide insights that may lead toward a solution. After exploring the appropriate literature, a decision is made about whether to continue to explore the question. If the scientist is still intrigued by the question, a formal hypothesis is constructed and the process of inquiry continues at a different level.

Constructing Hypotheses

A **hypothesis** is a statement that provides a possible answer to a question or an explanation for an observation that can be tested. A good hypothesis must be logical, account for all the relevant information currently available, allow one to predict future events relating to the question being asked, and be testable. Furthermore, if one has the choice of several competing hypotheses one should use the simplest hypothesis with the fewest assumptions. Just as deciding which questions to ask is often difficult, the formation of a hypothesis requires much critical thought and mental exploration. If the hypothesis does not account for all the observed facts in the situation, doubt will be cast on the work and may eventually cast doubt on the validity of the scientist's work. If a hypothesis is not

Table 1.1

THE NATURE OF THE SCIENTIFIC METHOD

Component of Science Process	Description of Process	Example of the Process in Action
Observation	Recognize something has happened and that it occurs repeatedly. (Empirical evidence is gained from experience or observation.)	Doctors observe that many of their patients, who are suffering from tuberculosis, fail to be cured by the use of the medicines (antibiotics) traditionally used to treat the disease.
Question formulation	Ask questions about the observation, evaluate the questions, and keep the ones that will be answerable.	Have the drug companies modified the antibiotics? Are the patients failing to take the antibiotics as prescribed? Has the bacterium that causes tuberculosis changed?
Exploration of alternative resources	Go to the library to obtain information about this observation. Talk to others who are interested in the same problem. Visit other researchers or communicate via letter, fax, or computer to help determine if your question is a good one or if others have already explored the topic.	Read medical journals. Contact the Centers for Disease Control and Prevention. Consult experts in tuberculosis. Attend medical conventions. Contact drug companies and ask if their antibiotic formulation has been changed.
Hypothesis formation	Pose a possible answer to your question. Be sure that it is testable and that it accounts for all the known information. Recognize that your hypothesis may be wrong.	Tuberculosis patients who fail to be cured by standard antibiotics have tuberculosis caused by antibiotic resistant populations of the bacterium *Mycobacterium tuberculosis*.
Test hypothesis (Experimentation)	Set up an experiment that will allow you to test your hypothesis using a control group and an experimental group. Be sure to collect and analyze the data carefully.	Set up an experiment in which samples of tuberculosis bacteria are collected from two groups of patients; those who are responding to antibiotic therapy but still have bacteria and those who are not responding to antibiotic therapy. Grow the bacteria in the lab and subject them to the antibiotics normally used. Use a large number of samples. The bacteria from the patients who are responding positively to the antibiotics are the control. The samples from those that are not responding constitute the experimental group. Experiments consistently show those patients who are not recovering have strains of bacteria that are resistant to the antibiotic being used.
Agreement with existing scientific laws and theories Or New laws or theories are constructed	If your findings are seen to fit with other major blocks of information that tie together many different kinds of scientific information, they will be recognized by the scientific community as being consistent with current scientific laws and theories. In rare instances, a new theory or law may develop as a result of research.	Your results are consistent with the following laws and theories: Mendel's laws of heredity state that characteristics are passed from parent to offspring during reproduction. The theory of natural selection predicts that when populations of organisms like *Mycobacterium tuberculosis* are subjected to something that kills many individuals in the population, those individuals that survive and reproduce will pass on the characteristics that allowed them to survive to the next generation and that the next generation will have a higher incidence of the characteristics. The discovery of the structure of DNA and subsequent research has led to the development of a major new theory and has led to a much more clear understanding of how changes (mutations) occur to genes.
Conclusion and communication	You arrive at a conclusion. Throughout the process, communicate with other scientists both by informal conversation and formal publications.	You conclude that the antibiotics are ineffective because the bacteria are resistant to the antibiotics. This could be because some of the individual bacteria contained altered DNA (mutation) that allowed them to survive in the presence of the antibiotic. They survived and reproduced passing their resistance to their offspring and building a population of antibiotic resistant tuberculosis bacteria. A scientific article is written describing the experiment and your conclusions.

testable or is not supported by the evidence, the explanation will be only hearsay and no more useful than mere speculation.

Keep in mind that a hypothesis is based on observations and information gained from other knowledgeable sources and predicts how an event will occur under specific circumstances. Scientists test the predictive ability of a hypothesis to see if the hypothesis is supported or is disproved. If you disprove the hypothesis, it is rejected and a new hypothesis must be constructed. However, if you cannot disprove a hypothesis, it increases your confidence in the hypothesis, but it does not prove it to be true in all cases and for all time. Science always allows for the questioning of ideas and the substitution of new ones that more completely describe what is known at a particular point in time. It could be that an alternative hypothesis you haven't thought of explains the situation or you have not made the appropriate observations to indicate that your hypothesis is wrong.

Testing Hypotheses

The test of a hypothesis can take several forms. It may simply involve the collection of pertinent information that already exists from a variety of sources. For example if you visited a cemetery and observed from reading the tombstones that an unusually large number of people of different ages died in the same year, you could hypothesize that there was an epidemic of disease or a natural disaster that caused the deaths. Consulting historical newspaper accounts would be a good way to test this hypothesis.

In other cases a hypothesis may be tested by simply making additional observations. For example, if you hypothesized that a certain species of bird used cavities in trees as places to build nests, you could observe several birds of the species and record the kinds of nests they built and where they built them.

Another common method for testing a hypothesis involves devising an experiment. An **experiment** is a re-creation of an event or occurrence in a way that enables a scientist to support or disprove a hypothesis. This can be difficult because a particular event may involve a great many separate happenings called **variables.** For example, the production of songs by birds involves many activities of the nervous system and the muscular system and is stimulated by a wide variety of environmental factors. It might seem that developing an understanding of the factors involved in birdsong production is an impossible task. To help unclutter such situations, scientists use what is known as a *controlled experiment.*

A **controlled experiment** allows scientists to construct a situation so that only one variable is present. Furthermore, the variable can be manipulated or changed. A typical controlled experiment includes two groups; one in which the variable is manipulated in a particular way and another in which there is no manipulation. The situation in which there is no manipulation of the variable is called the **control group;** the other situation is called the **experimental group.**

The situation involving birdsong production would have to be broken down into a large number of simple questions, such as: Do both males and females sing? Do they sing during all parts of the year? Is the song the same in all cases? Do some individuals sing more than others? What anatomical structures are used in singing? What situations cause birds to start or stop singing? Each question would provide the basis for the construction of a hypothesis which could be tested by an experiment. Each experiment would provide information about a small part of the total process of birdsong production. For example, in order to test the hypothesis that male sex hormones produced by the testes are involved in stimulating male birds to sing, an experiment could be performed in which one group of male birds had their testes removed (the experimental group), whereas the control group was allowed to develop normally. The presence or absence of testes is manipulated by the scientist in the experiment and is known as the **independent variable.** The singing behavior of the males is called the **dependent variable** because if sex hormones are important, the singing behavior observed will change depending on whether the males have testes or not (the independent variable). In an experiment there should only be one independent variable and the dependent variable is expected to change as a direct result of manipulation of the independent variable. After the experiment, the new data (facts) gathered would be analyzed. If there were no differences in singing between the two groups, scientists could conclude that the independent variable evidently did not have a cause-and-effect relationship with the dependent variable (singing). However, if there was a difference, it would be likely that the independent variable was responsible for the difference between the control and experimental groups. In the case of songbirds, removal of the testes does change their singing behavior.

Scientists are not likely to accept the results of a single experiment because it is possible a random event that had nothing to do with the experiment could have affected the results and caused people to think there was a cause-and-effect relationship when none existed. For example, the operation necessary to remove the testes of male birds might cause illness or discomfort in some birds, resulting in less singing. A way to overcome this difficulty would be to subject all birds to the same surgery but to remove the testes of only half of them. (The control birds would still have their testes.) Only when there is just one variable, many replicates (copies) of the same experiment are conducted, and the results are consistently the same; are the results of the experiment considered convincing.

Furthermore, scientists often apply statistical tests to the results to help decide in an impartial manner if the results obtained are **valid** (meaningful, fit with other knowledge) and **reliable** (give the same results repeatedly) and show cause and effect, or if they are just the result of random events.

During experimentation, scientists learn new information and formulate new questions that can lead to even more

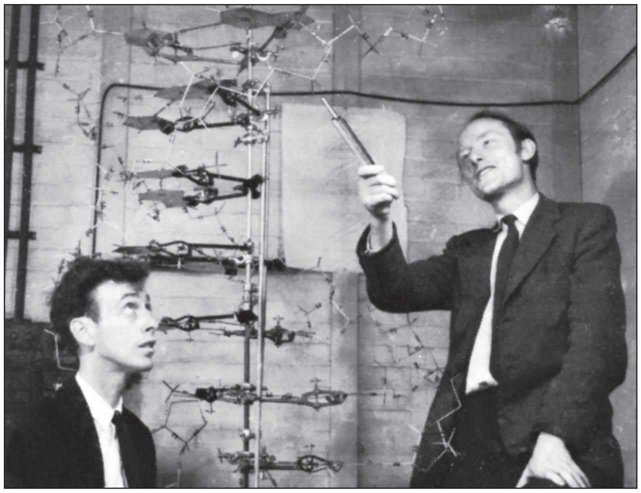


Figure 1.3

The Growth of Knowledge
James D. Watson and Francis W. Crick are theoretical scientists who, in 1953, determined the structure of the DNA molecule, which contains the genetic information of a cell. This photograph shows the model of DNA they constructed. The discovery of the structure of the DNA molecule was followed by much research into how the molecule codes information, how it makes copies of itself, and how the information is put into action.

experiments. One good experiment can result in 100 new questions and experiments. The discovery of the structure of the DNA molecule by Watson and Crick resulted in thousands of experiments and stimulated the development of the entire field of molecular biology (figure 1.3). Similarly, the discovery of molecules that regulate the growth of plants resulted in much research about how the molecules work and which molecules might be used for agricultural purposes.

If the processes of questioning and experimentation continue, and evidence continually and consistently supports the original hypothesis and other closely related hypotheses, the scientific community will begin to see how these hypotheses and facts fit together into a broad pattern. When this happens, a theory has come into existence.

The Development of Theories and Laws

A **theory** is a widely accepted, plausible generalization about fundamental concepts in science that explain *why* things happen. An example of a biological theory is the germ theory of disease. This theory states that certain diseases, called *infectious* diseases, are caused by living microorganisms that are capable of being transmitted from one individual to another. When these microorganisms reproduce within a person and their populations rise, they cause disease.

As you can see, this is a very broad statement that is the result of years of observation, questioning, experimentation, and data analysis. The germ theory of disease provides a broad overview of the nature of infectious diseases and methods for their control. However, we also recognize that each kind of microorganism has particular characteristics that determine the kind of disease condition it causes and the methods of treatment that are appropriate. Furthermore, we recognize that there are many diseases that are not caused by microorganisms.

Because we are so confident that the theory explains why some kinds of diseases spread from one person to another, we use extreme care to protect people from infectious microorganisms by treating drinking water, maintaining sterile surroundings when doing surgery, and protecting persons with weakened immune systems from sources of infection.

Theories and hypotheses are different. A hypothesis provides a possible explanation for a specific question; a theory is a broad concept that shapes how scientists look at the world and how they frame their hypotheses. For example, when a new disease is encountered, one of the first questions asked would be, “What causes this disease?” A hypothesis could be constructed that states, “The disease is caused by a microorganism.” This would be a logical hypothesis because it is consistent with the general theory that many kinds of diseases are caused by microorganisms (germ theory of disease). Because they are broad unifying statements, there are few theories. However, just because a theory exists does not mean that testing stops. As scientists continue to gain new information they may find exceptions to a theory or, even in rare cases, disprove a theory.

A **scientific law** is a uniform or constant fact of nature that describes *what* happens in nature. An example of a biological law is the biogenetic law, which states that all living things come from preexisting living things. While laws describe what happens and theories describe why things happen, in one way laws and theories are similar. They have both been examined repeatedly and are regarded as excellent predictors of how nature behaves.

In the process of sorting out the way the world works, scientists use generalizations to help them organize information. However, the generalizations must be backed up with facts. The relationship between facts and generalizations is a two-way street. Often as observations are made and hypotheses are tested, a pattern emerges which leads to a general conclusion, principle, or theory. This process of developing general principles from the examination of many sets of specific facts is called **induction** or **inductive reasoning.** For example, when people examine hundreds of species of birds, they observe that all kinds lay eggs. From these observations, they may develop the principle that egg laying is a fundamental characteristic of birds, without examining every single species of bird.

Once a rule, principle, or theory is established, it can be used to predict additional observations in nature. When general principles are used to predict the specific facts of a situation, the process is called **deduction** or **deductive reasoning.** For example, after the general principle that birds lay eggs is established, one could deduce that a newly discovered species of bird would also lay eggs. In the process of science, both induction and deduction are important thinking processes used to increase our understanding of the nature of our world.

Communication

One central characteristic of the scientific method is the importance of communication. For the most part science is conducted out in the open under the critical eyes of others who are interested in the same kinds of questions. An important part of the communication process involves the publication of articles in scientific journals about one's research, thoughts, and opinions. The communication can occur at any point during the process of scientific discovery.

People may ask questions about unusual observations. They may publish preliminary results of incomplete experiments. They may publish reports that summarize large bodies of material. And they often publish strongly held opinions that may not always be supportable with current data. This provides other scientists with an opportunity to criticize, make suggestions, or agree. Scientists attend conferences where they can engage in dialog with colleagues. They also interact in informal ways by phone, e-mail, and the Internet.

The result is that most of science is subjected to examination by many minds as it is discovered, discussed, and refined.

1.3 Science, Nonscience, and Pseudoscience

Fundamental Attitudes in Science

As you can see from this discussion of the scientific method, a scientific approach to the world requires a certain way of thinking. There is an insistence on ample supporting evidence by numerous studies rather than easy acceptance of strongly stated opinions. Scientists must separate opinions from statements of fact. A scientist is a healthy skeptic.

Careful attention to detail is also important. Because scientists publish their findings and their colleagues examine their work, they have a strong desire to produce careful work that can be easily defended. This does not mean that scientists do not speculate and state opinions. When they do, however, they take great care to clearly distinguish fact from opinion.

There is also a strong ethic of honesty. Scientists are not saints, but the fact that science is conducted out in the open in front of one's peers tends to reduce the incidence of dishonesty. In addition, the scientific community strongly condemns and severely penalizes those who steal the ideas of others, perform shoddy science, or falsify data. Any of these infractions could lead to the loss of one's job and reputation.

From Discovery to Application

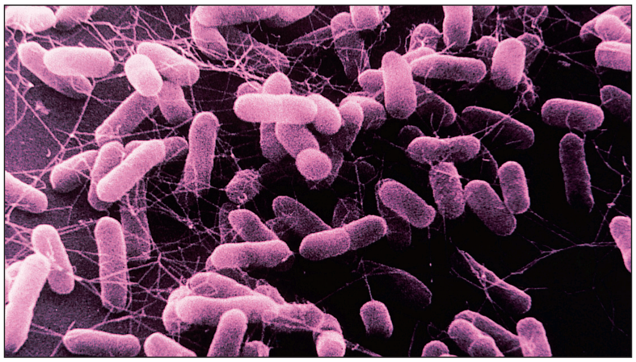
The scientific method has helped us understand and control many aspects of our natural world. Some information is extremely important in understanding the structure and functioning of things in our world but at first glance appears to have little practical value. For example, understanding the life cycle of a star or how meteors travel through the universe may be important for people who are trying to answer questions about how the universe was formed, but it seems of little value to the average citizen. However, as our knowledge has increased, the time between first discovery to practical application has decreased significantly.

For example, scientists known as *genetic engineers* have altered the chemical code system of small organisms (microorganisms) so that they may produce many new drugs such as antibiotics, hormones, and enzymes. The ease with which these complex chemicals are produced would not have been possible had it not been for the information gained from the basic, theoretical sciences of microbiology, molecular biology, and genetics (figure 1.4). Our understanding of how organisms genetically control the manufacture of proteins has led to the large-scale production of enzymes. Some of these chemicals can remove stains from clothing, deodorize, clean contact lenses, remove damaged skin from burn patients, and "stone wash" denim for clothing.

Another example that illustrates how fundamental research can lead to practical application is the work of Louis Pasteur, a French chemist and microbiologist. Pasteur was interested in the theoretical problem of whether life could be generated from nonliving material. Much of his theoretical work led to practical applications in disease control. His theory that there are microorganisms that cause diseases and decay led to the development of vaccinations against rabies and the development of pasteurization for the preservation of foods (figure 1.5).

Science and Nonscience

Both scientists and nonscientists seek to gain information and improve understanding of their fields of study. The differences between science and nonscience are based on the assumptions and methods used to gather and organize information and, most important, the way the assumptions are tested. The difference between a scientist and a nonscientist is that a scientist continually challenges and tests principles and assumptions to determine a cause-and-effect relationship, whereas a nonscientist may not be able to do so or may not believe that this is important. For example, a historian may have the opinion that if President Lincoln had not appointed Ulysses S. Grant to be a General in the Union Army, the Confederate States of America would have won the Civil War. Although there can be considerable argument about the topic, there is no way that it can be tested. Therefore, it is not scientific. This does not mean that history is not a respectable field of study. It is just not science.



(a)

(b)

Figure 1.4

Genetic Engineering
Genetic engineers have modified the genetic code of bacteria, like *Escherichia coli,* commonly found in the colon (*a*) to produce useful products such as vitamins, protein, and antibiotics. The bacteria can be cultured in special vats where the genetically modified bacteria manufacture their products (*b*). The products can be extracted from the mixture in the vat.

Figure 1.5

Louis Pasteur and Pasteurized Milk
Louis Pasteur (1822–1895) performed many experiments while he studied the question of the origin of life, one of which led directly to the food-preservation method now known as pasteurization.

Once you understand the scientific method, you won't have any trouble identifying astronomy, chemistry, physics, and biology as sciences. But what about economics, sociology, anthropology, history, philosophy, and literature? All of these fields may make use of certain central ideas that are derived in a logical way, but they are also nonscientific in some ways. Some things are beyond science and cannot be approached using the scientific method. Art, literature, theology, and philosophy are rarely thought of as sciences. They are concerned with beauty, human emotion, and speculative thought rather than with facts and verifiable laws. On the other hand, physics, chemistry, geology, and biology are almost always considered sciences.

Many fields of study have both scientific and nonscientific aspects. The style of clothing worn is often shaped by the artistic creativity of designers and shrewd marketing by retailers. Originally, animal hides, wool, cotton, and flax were the only materials available and the choice of color was limited to the natural color of the material or dyes extracted from nature. The development of synthetic fabrics and dyes, machines to construct clothing, and new kinds of fasteners allowed for new styles and colors (figure 1.6). Similarly, economists use mathematical models and established economic laws to make predictions about future economic conditions. However, the reliability of predictions is a central criterion of science, so the regular occurrence of unpredicted economic changes indicates that economics is far from scientific. Many aspects of anthropology and sociology are scientific in nature but they cannot be considered true sciences because many of the generalizations in these fields cannot be tested by repeated experimentation. They also do not show a significantly high degree of cause and effect, or they have poor predictive value.

Pseudoscience

Pseudoscience (*pseudo* = false) is not science but uses the appearance or language of science to convince, confuse, or mislead people into thinking that something has scientific validity. When pseudoscientific claims are closely examined,

(a) (b)

Figure 1.6

Science and Culture
While the design of clothing is not a scientific enterprise, scientific discoveries have altered the possible choices available. (*a*) Originally, clothing could only be made from natural materials with simple construction methods. (*b*) The discovery of synthetic fabrics and dyes and the invention of specialized fasteners resulted in increased variety and specialization of clothing.

Figure 1.7

"Nine out of Ten Doctors Surveyed Recommend Brand X"
It is obvious that there are many things wrong with this statement. First of all, is the person in the white coat a physician? Second, if only 10 doctors were asked, the sample size is too small. Third, only selected doctors might have been asked to participate. Finally, the question could have been asked in such a way as to obtain the desired answer: "Would you recommend brand X over Dr. Pete's snake oil?"

it is found that they are not supportable as valid or reliable. The area of nutrition is a respectable scientific field, however, there are many individuals and organizations that make unfounded claims about their products and diets (figure 1.7).

We all know that we must obtain certain nutrients like amino acids, vitamins, and minerals from the food we eat or we may become ill. Many scientific experiments have been performed that reliably demonstrate the validity of this information. However, in most cases, it has not been demonstrated that the nutritional supplements so vigorously advertised are as useful or desirable as advertised. Rather, selected bits of scientific information (amino acids, vitamins, and minerals are essential to good health) have been used to create the feeling that additional amounts of these nutritional supplements are necessary or that they can improve your health. In reality, the average person eating a varied diet will obtain all of these nutrients in adequate amounts and nutritional supplements are not required.

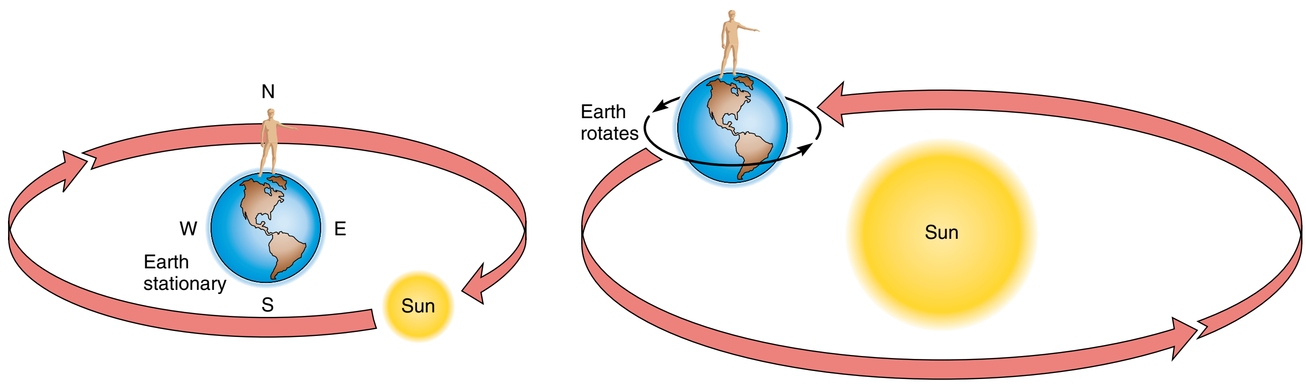
In addition, many of these products are labeled as organic or natural, with the implication that they have greater nutritive value because they are organically grown (grown without pesticides or synthetic fertilizers) or because they come from nature. The poisons curare, strychnine, and nicotine are all organic molecules that are produced in nature by plants that can be grown organically, but we wouldn't want to include them in our diet.

Limitations of Science

By definition, science is a way of thinking and seeking information to solve problems. Therefore the scientific method can be applied only to questions that have factual bases. Questions concerning morals, value judgments, social issues, and attitudes cannot be answered using the scientific method. What makes a painting great? What is the best type of music? Which wine is best? What color should I paint my car? These questions are related to values, beliefs, and tastes; therefore, the scientific method cannot be used to answer them.

Science is also limited by the ability of people to pry understanding from the natural world. People are fallible and do not always come to the right conclusions because information is lacking or misinterpreted, but science is self-correcting. As new information is gathered, old incorrect ways of thinking must be changed or discarded. For example, at one time scientists were sure that the Sun went around the Earth. They observed that the Sun rose in the east and traveled across the sky to set in the west. Because scientists could not feel the Earth moving it seemed perfectly logical that the Sun traveled around the Earth. Once they understood that the Earth rotated on its axis, they began to realize that the rising and setting of the Sun could be explained in other ways. A completely new concept of the relationship between the Sun and the Earth developed (figure 1.8).

Although this kind of study seems rather primitive to us today, this change in thinking about the Sun and the



Scientists thought that the Sun revolved around the Earth. We now know that the Earth rotates on its axis and also revolves around the Sun.

Figure 1.8

Science Must Be Willing to Challenge Previous Beliefs
Science always must be aware that new discoveries may force a reinterpretation of previously held beliefs. Early scientists thought that the Sun revolved around the Earth in a clockwise direction. This was certainly a reasonable theory at the time. Subsequently, we have learned that the Earth revolves around the Sun in a counterclockwise direction, at the same time rotating on its axis in a counterclockwise direction. This rotation of the Earth on its axis gives us the impression that the Sun is moving.

Earth was a very important step toward understanding the universe and how the various parts are related to one another. This background information was built upon by many generations of astronomers and space scientists, and finally led to space exploration.

People need to understand that science cannot answer all the problems of our time. Although science is a powerful tool there are many questions it cannot answer and many problems it cannot solve. Most of the problems societies face are generated by the behavior and desires of people. Famine, drug abuse, and pollution are human-caused and must be resolved by humans. Science may provide some tools for social planners, politicians, and ethical thinkers, but science does not have, nor does it attempt to provide, all the answers to the problems of the human race. Science is merely one of the tools at our disposal.

1.4 The Science of Biology

The science of biology is, broadly speaking, the study of living things. It draws on chemistry and physics for its foundation and applies these basic physical laws to living things. Because there are many kinds of living things, there are many special areas of study in biology. Practical biology—such as medicine, crop science, plant breeding, and wildlife management—is balanced by more theoretical biology—such as medical microbiological physiology, photosynthetic biochemistry, plant taxonomy, and animal behavior (ethology). There is also just plain fun biology like insect collecting and bird watching. Specifically, biology is a science that deals with living things and how they interact with their surroundings.

At the beginning of the chapter, biology was defined as the science that deals with living things. But what does it mean to be alive? You would think that a biology textbook could answer this question easily. However, this is more than just a theoretical question because in recent years it has been necessary to construct legal definitions of what life is and especially of when it begins and ends. The legal definition of death is important because it may determine whether a person will receive life insurance benefits or if body parts may be used in transplants. In the case of heart transplants, the person donating the heart may be legally "dead," but the heart certainly isn't. It is removed while it still has "life," even though the person is not "alive." In other words, there are different kinds of death. There is the death of the whole living unit and the death of each cell within the living unit. A person actually "dies" before every cell has died. Death, then, is the absence of life, but that still doesn't tell us what life is. At this point, we won't try to define life but we will describe some of the basic characteristics of living things.

Characteristics of Life

Living things have special abilities and structures not typically found in things that were never living. The ability to manipulate energy and matter is unique to living things. **Energy** is the ability to do work or cause things to move. **Matter** is anything that has mass and takes up space. Developing an understanding of how living things modify matter and use energy will help you appreciate how living things differ from nonliving objects. Living things show five characteristics that the nonliving do not display: (1) metabolic processes, (2) generative processes, (3) responsive processes,

(4) control processes, and (5) a unique structural organization. It is important to recognize that while these characteristics are typical of all living things, they may not necessarily all be present in each organism at every point in time. For example, some individuals may reproduce or grow only at certain times. This section gives a brief introduction to the basic characteristics of living things that will be expanded upon in the rest of the text.

Metabolic processes involve the total of all chemical reactions and associated energy changes that take place within an organism. This set of reactions is often simply referred to as **metabolism** (*metabolism* = Greek *metaballein,* to turn about, change, alter). Energy is necessary for movement, growth, and many other activities. The energy that organisms use is stored in the chemical bonds of complex molecules. The chemical reactions used to provide energy and raw materials to organisms are controlled and sequenced. There are three essential aspects of metabolism: (1) *nutrient uptake,* (2) *nutrient processing,* and (3) *waste elimination.* All living things expend energy to take in nutrients (raw materials) from their environment. Many animals take in these materials by eating or swallowing other organisms. Microorganisms and plants absorb raw materials into their cells to maintain their lives. Once inside, nutrients enter a network of chemical reactions. These reactions manipulate nutrients in order to manufacture new parts, make repairs, reproduce, and provide energy for essential activities. However, not all materials entering a living thing are valuable to it. There may be portions of nutrients that are useless or even harmful. Organisms eliminate these portions as waste. These metabolic processes also produce unusable heat energy, which may be considered a waste product.

Generative processes are activities that result in an increase in the size of an individual organism—*growth*—or an increase in the number of individuals in a population of organisms—*reproduction.* During growth, living things add to their structure, repair parts, and store nutrients for later use. Growth and reproduction are directly related to metabolism because neither can occur without gaining and processing nutrients. Since all organisms eventually die, life would cease to exist without reproduction. There are a number of different ways that various kinds of organisms reproduce and guarantee their continued existence. Some kinds of living things reproduce by *sexual reproduction* in which two individuals contribute to the creation of a unique, new organism. *Asexual reproduction* occurs when an individual organism makes identical copies of itself.

Organisms also respond to changes within their bodies and in their surroundings in a meaningful way. These **responsive processes** have been organized into three categories: *irritability, individual adaptation,* and *adaptation of populations,* which is also known as *evolution.*

Irritability is an individual's ability to recognize a stimulus and rapidly respond to it, such as your response to a loud noise, beautiful sunset, or noxious odor. The response occurs only in the individual receiving the stimulus and the reaction is rapid because the structures and processes that cause the response to occur (i.e., muscles, bones, and nerves) are already in place.

Individual adaptation also results from an individual's reaction to a stimulus but is slower because it requires growth or some other fundamental change in an organism. For example, when the days are getting shorter a weasel responds such that its fur color will change from its brown summer coat to its white winter coat—genes responsible for the production of brown pigment are "turned off" and new white hair grows. Similarly, the response of our body to disease organisms requires a change in the way cells work to attack and eventually destroy the disease-causing organism. Or the body responds to lower oxygen levels by producing more red blood cells, which carry oxygen. This is why athletes like to train at high elevations. Their ability to transport oxygen to muscles is improved by the increased number of red blood cells.

Evolution involves changes in the kinds of characteristics displayed by individuals within the population. It is a slow change in the genetic makeup of a *population* of organisms over generations. This process occurs over long periods of time and enables a species (population of a specific kind of organism) to adapt and better survive long-term changes in its environment over many generations. For example, the development of structures that enable birds to fly long distances, allow them to respond to a world in which the winter season presents severe conditions that would threaten survival. Similarly, the development of the human brain and the ability to reason allowed our ancestors to craft and use tools. The use of tools allowed them to survive and be successful in a great variety of environmental conditions.

Control processes are mechanisms that ensure an organism will carry out all metabolic activities in the proper sequence (*coordination*) and at the proper rate (*regulation*). All the chemical reactions of an organism are coordinated and linked together in specific pathways. The orchestration of all the reactions ensures that there will be specific stepwise handling of the nutrients needed to maintain life. The molecules responsible for coordinating these reactions are known as *enzymes.* **Enzymes** are molecules, produced by organisms, that are able to increase and control the rate at which life's chemical reactions occur. Enzymes also regulate the amount of nutrients processed into other forms. The physical activities of organisms are coordinated also. When an insect walks, the activities of the muscles of its six legs are coordinated so that an orderly movement results.

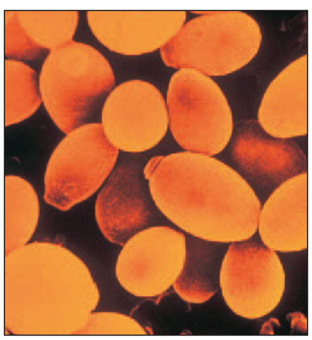
Many of the internal activities of organisms are interrelated and coordinated so that a constant internal environment is maintained. This constant internal environment is called **homeostasis.** For example, when we begin to exercise we use up oxygen more rapidly so the amount of oxygen in the blood falls. In order to maintain a "constant internal environment" the body must obtain more oxygen. This involves more rapid contractions of the muscles that cause breathing and a more rapid and forceful pumping of the heart to get blood to the lungs. These activities must occur together at the right time and at the correct rate, and when they do, the level of oxygen in the blood will remain normal while supporting the additional muscular activity.

Living things also share basic structural similarities. All living things are made up of complex, structural units called **cells.** Cells have an outer limiting membrane and several kinds of internal structures. Each structure has specific functions. Some living things, like you, consist of trillions of cells while others, such as bacteria or yeasts, consist of only one cell. Any unit that is capable of functioning independently is called an **organism,** whether it consists of a single cell or complex groups of interacting cells (figure 1.9). Nonliving materials, such as rocks, water, or gases, do not share a structurally complex common subunit. Figure 1.10 summarizes the characteristics of living things.

Levels of Organization

Biologists and other scientists like to organize vast amounts of information into conceptual chunks that are easier to relate to one another. One important concept in biology is that all living things share the structural and functional characteristics we have just discussed. Another important organizing concept is that organisms are special kinds of matter that interact with their surroundings at several different levels (table 1.2). When biologists seek answers to a particular problem they may attack it at several different levels simultaneously. They must understand the molecules that make up living things, how the molecules are incorporated into cells, how tissues, organ, or systems within an organism function, and how populations and ecosystems are affected by changes in individual organisms.

For example, in the 1950s people began to notice a decline in the populations of certain kinds of birds. In 1962 Rachel Carson wrote a book entitled *Silent Spring* in which she linked the use of certain kinds of persistent pesticides with the changes in populations of animals. This controversial book launched the modern environmental movement and led to a great deal of research on the impact of persistent organic molecules on living things. The pesticide, DDT, which has been banned from use in much of the world because of its effects on populations of animals, presents a good case study to illustrate how biologists must be aware of the different levels of organization when studying a particular problem. DDT is an organic molecule that dissolves readily in fats and oils. It is also a molecule that does not break down very quickly. Therefore, once it is present it will continue to have its effects for years. Since DDT dissolves in oils, it is often concentrated in the fatty portions of animals, and when a carnivore eats an animal with DDT in its fat, the carnivore receives an increased dose of the toxin. Birds are particularly affected by DDT, since it interferes with the ability of many kinds of birds to synthesize egg shells. Carnivorous birds like eagles are particularly vulnerable to



Yeast

Euplotes

Humans

Orchid

Figure 1.9

An Organism Can Be Simple or Complex
Each individual organism, whether it is simple or complex, is able to independently carry on metabolic, generative, responsive, and control processes. Some organisms, like yeast or the protozoan *Euplotes,* consist of single cells while others, like orchids and humans, consist of many cells organized into complex structures.

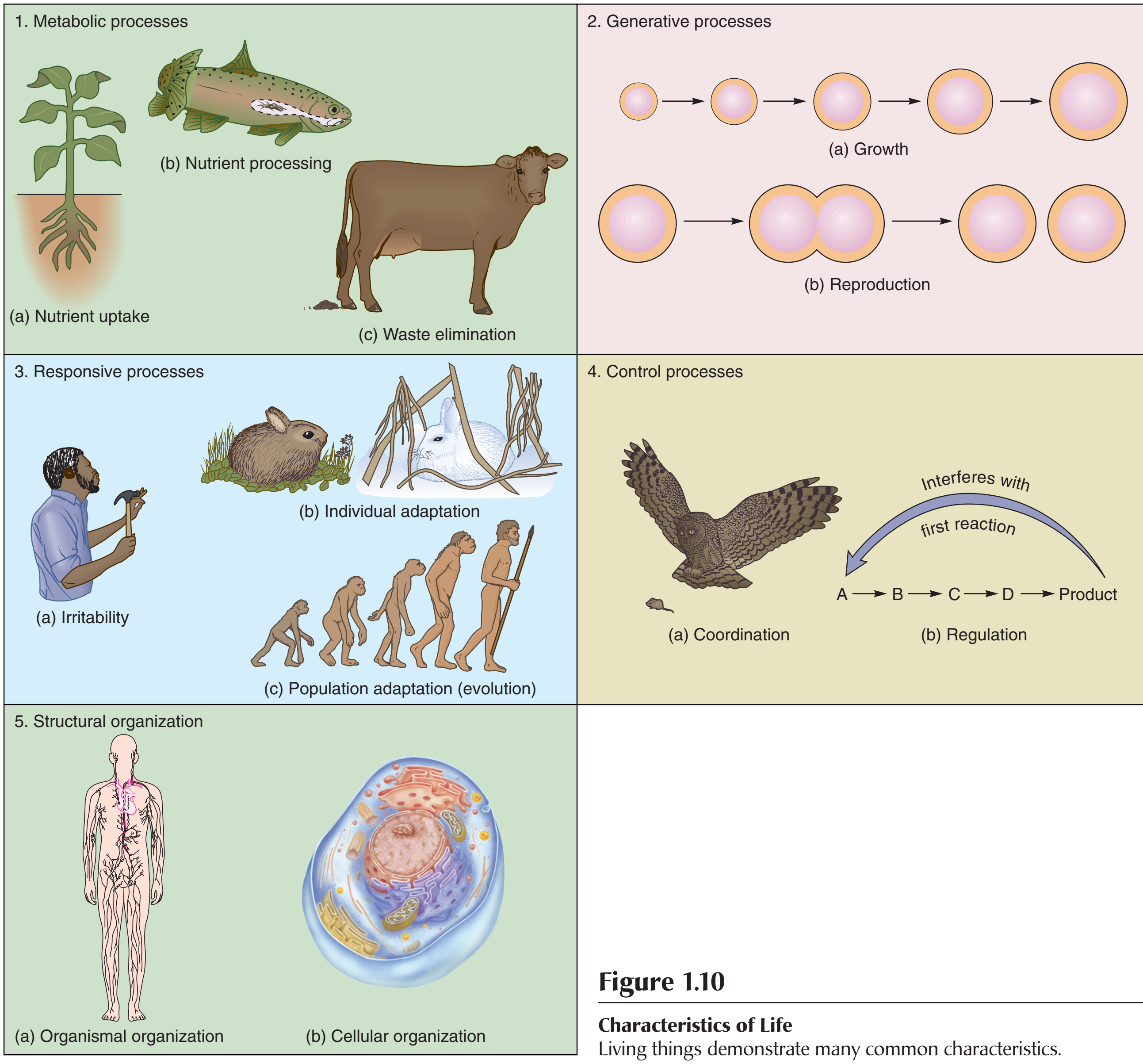


Figure 1.10

Characteristics of Life
Living things demonstrate many common characteristics.

increased levels of DDT in their bodies, because carnivores consume fats from their prey. Fragile shells are easily broken and the ability of the birds to reproduce falls sharply and their populations fall.

Thus, determining why the populations of certain birds were falling, involved: (1) knowledge of the nature of the molecules involved, (2) how the affected animals interacted in a community of organisms, (3) where DDT was found in the bodies of animals, (4) what organ systems it affected, and ultimately (5) how it affected the ability of specialized cells to produce egg shells.

The Significance of Biology

To a great extent, we owe our current high standard of living to biological advances in two areas: food production and disease control. Plant and animal breeders have developed organisms that provide better sources of food than the original varieties. One of the best examples of this is the changes that have occurred in corn. Corn is a grass that produces its seed on a cob. The original corn plant had very small ears that were perhaps only three or four centimeters long. Through selective breeding, varieties of corn with much larger ears and more

Table 1.2

LEVELS OF ORGANIZATION FOR LIVING THINGS

Category	Characteristics/Explanation	Example/Application
Biosphere	The worldwide ecosystem	Human activity affects the climate of the Earth. Global climate change, hole in ozone layer
Ecosystem	Communities (groups of populations) that interact with the physical world in a particular place	The Everglades ecosystem involves many kinds of organisms, the climate, and the flow of water to south Florida.
Community	Populations of different kinds of organisms that interact with one another in a particular place	The populations of trees, insects, birds, mammals, fungi, bacteria, and many other organisms that interact in any location
Population	A group of individual organisms of a particular kind	The human population currently consists of about 6 billion individual organisms. The current population of the California condor is about 200 individuals.
Individual organism	An independent living unit	A single organism Some organisms consist of many cells—you, a morel mushroom, a rose bush. Others are single cells—yeast, pneumonia bacterium, *Amoeba*.
Organ system	Groups of organs that perform particular functions	The circulatory system consists of a heart, arteries, veins, and capillaries, all of which are involved in moving blood from place to place.
Organ	Groups of tissues that perform particular functions	An eye contains nervous tissue, connective tissue, blood vessels, and pigmented tissues, all of which are involved in sight.
Tissue	Groups of cells that perform particular functions	Blood, groups of muscle cells, and the layers of the skin are all groups of cells that perform a particular function.
Cell	The smallest unit that displays the characteristics of life	Some organisms are single cells. Within multicellular organisms there are several kinds of cells—heart muscle cells, nerve cells, white blood cells.
Molecules	Specific arrangements of atoms	Living things consist of special kinds of molecules, such as proteins, carbohydrates, and DNA.
Atoms	The fundamental units of matter	Hydrogen, oxygen, nitrogen and about 100 others

seeds per cob have been produced. This has increased the yield greatly. In addition, the corn plant has been adapted to produce other kinds of corn, such as sweet corn and popcorn.

Corn is not an isolated example. Improvements in yield have been brought about in wheat, rice, oats, and other cereal grains. The improvements in the plants, along with changed farming practices (also brought about through biological experimentation), have led to greatly increased production of food.

Animal breeders also have had great successes. The pig, chicken, and cow of today are much different animals from those available even 100 years ago. Chickens lay more eggs, dairy cows give more milk, and beef cattle grow faster (figure 1.11). All of these improvements raise our standard of

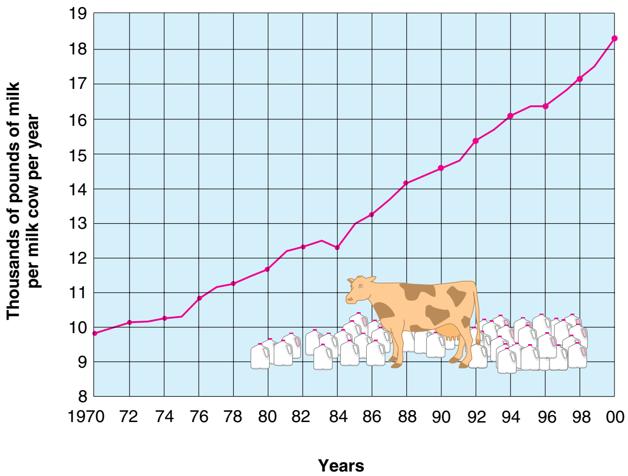


Figure 1.11

Biological Research Contributes to Increased Food Production
This graph illustrates a steady increase in milk yield, largely because of changing farming practices and selective breeding programs.

Data from the U.S. Department of Agriculture, *National Agricultural Statistics.*

living. One interesting example is the change in the kinds of hogs that are raised. At one time, farmers wanted pigs that were fatty. The fat could be made into lard, soap, and a variety of other useful products. As the demand for the fat products of pigs declined, animal breeders developed pigs that gave a high yield of meat and relatively little fat. Today, plant and animal breeders can produce plants and animals almost to specifications.

Much of the improvement in food production has resulted from the control of plants and animals that compete with or eat the organisms we use as food. Control of insects and fungi that weaken plants and reduce yields is as important as the invention of new varieties of plants. Because these are "living" pests, biologists have been involved in the study of them also.

There has been fantastic progress in the area of health and disease control. Many diseases, such as polio, whooping cough, measles, and mumps, can be easily controlled by vaccinations or "shots" (How Science Works 1.1). Unfortunately, the vaccines have worked so well that some people no longer worry about getting the shots, and some of these diseases, such as diphtheria, are reappearing. These diseases have not been eliminated, and people who are not protected by vaccinations are still susceptible to them.

The understanding of how the human body works has led to treatments that can control such diseases as diabetes, high blood pressure, and even some kinds of cancer. Paradoxically, these advances contribute to a major biological problem: the increasing size of the human population.

Consequences of Not Understanding Biological Principles

Now we will look at some of the problems that have been created by well-intentioned individuals who inadequately understood or inappropriately applied biological principles.

As European settlers spread over North America in the eighteenth and nineteenth centuries, they utilized natural resources such as timber, coal, game, oil, and soil. As long as the human population remained small and dispersed, many of these resources could be sustained by regrowth or reproduction—thus they are called renewable resources (e.g., timber, game, soil). The supply of nonrenewable resources such as oil and coal appeared to be large enough to last for centuries. However, as the population increased and demands for these resources grew, a need to conserve our resources for future generations became clear. Maintaining the balance of nature would allow for the regrowth and reproduction of renewable resources. To this end, the first national park (Yellowstone) was established in 1872. At the time, people thought the idea of "setting aside" a piece of the landscape in this fashion was a great way to solve the problem of scarce resources. Since that time millions of acres of deserts, forests, mountain ranges, and prairies have been designated as preserves, monuments, parks, and national forests. It was believed that by compartmentalizing our country we could keep harmful influences away from these areas and preserve dwindling resources for the future.

With the passage of time, scientists have recognized that compartmentalizing our land does not keep harmful things from happening inside the parks. Damage resulting from human activities outside these "preserves" has crept across our artificial boundaries. Some of the damage has been severe. For example, although Everglades National Park in Florida has been well managed by the National Park Service, this ecosystem is experiencing significant destruction. Commercial and agricultural development adjacent to the park have caused groundwater levels in the Everglades to drop so low that the very existence of the park is threatened. In addition, fertilizer has entered the park from surrounding farmland and encouraged the growth of plants that change the nature of the ecosystem. In 2000, Congress authorized the expenditure of $1.4 billion to begin to implement a plan that will address the problems of water flow and pollution.

The historic emphasis on managing forests for timber production has also caused concerns about the degradation of ecosystems. The Pacific Northwest (Washington, Oregon, British Columbia, and northern California) presents an example. The practice of clear-cutting (stripping the forest of all trees) large regions of forest for lumber and paper pulp appears to be the cause. It has negatively affected many people as well as the animal and plant life in the region. Clear-cutting to the edge of streams has resulted in decreases in the populations of salmon and other important organisms. Satellite photos as well as photos taken from aircraft reveal extensive ecosystem destruction (figure 1.12).

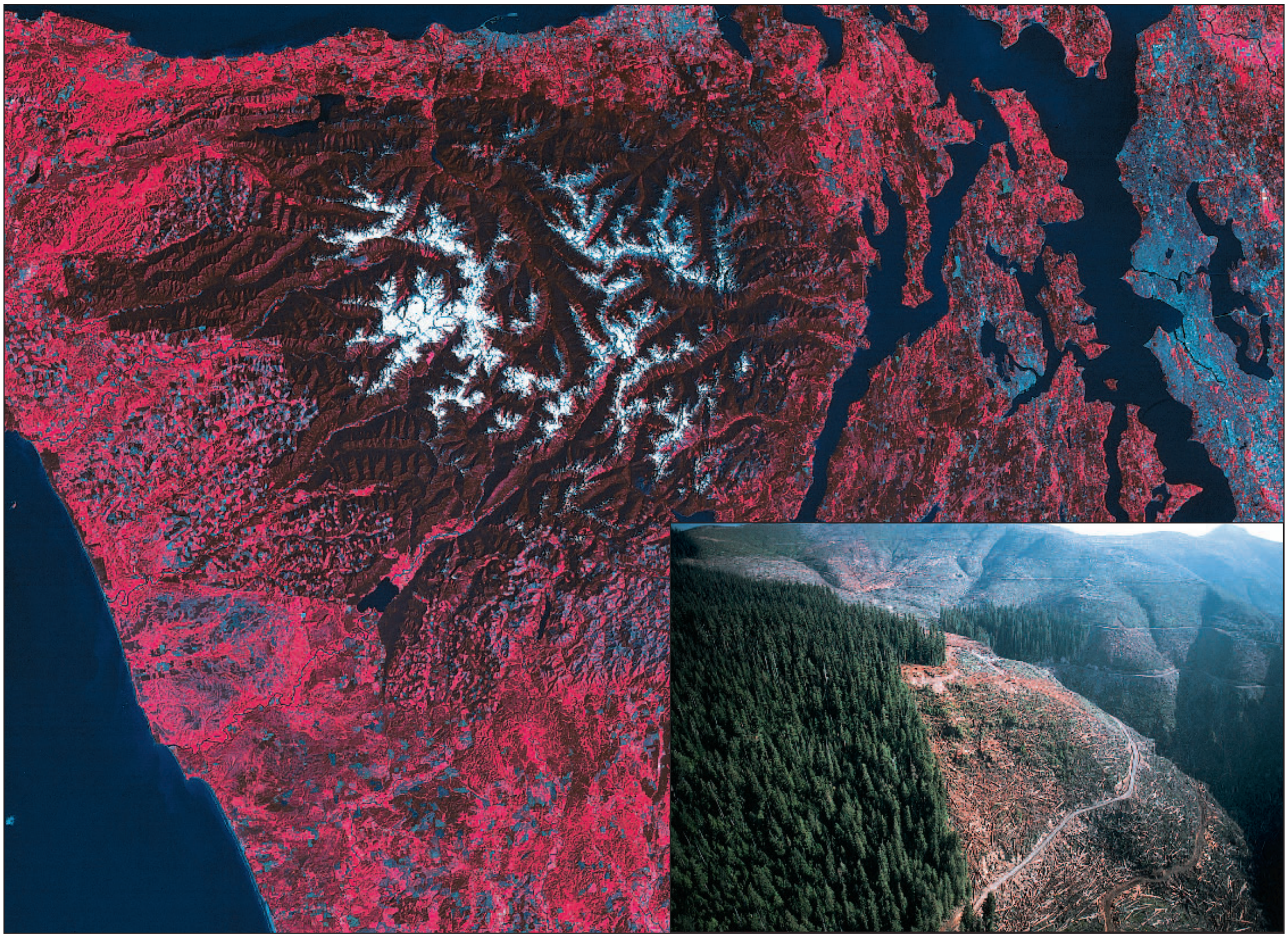


Figure 1.12

Effects of Clear-Cutting on Forests
This satellite photo of Washington's Olympic Peninsula shows the extent of deforestation resulting from commercial timber harvesting. The darker shades of red indicate forested regions, lighter shades show recent growth, and the light blue highlights deforested areas. The photo inset is a typical clear-cut area and corresponds to the light blue in the satellite photo.

Scientists working in conjunction with the federal government have now proposed a long-term, regional approach they hope will bring the ecosystems of the region back into balance. This approach takes into consideration all species, including humans, and the needs of each to utilize the natural resources of the region.

Another problem has been caused by the introduction of exotic (foreign) species of plants and animals. In North America, this has had disastrous consequences in a number of cases. Both the American chestnut and the American elm have been nearly eliminated by diseases that were introduced by accident. Other organisms have been introduced on purpose because of shortsightedness or a total lack of understanding about biology. The starling and the English (house) sparrow were both introduced into this country by people who thought that they were doing good. Both of these birds have multiplied greatly and have displaced some native birds. The gypsy moth is also an introduced species; the moths were brought to the United States by silk manufacturers in hopes of interbreeding the gypsy moth with the silkworm moth to increase silk production. When the scheme fell short of its goal and moths were accidentally set free, the moths quickly took advantage of their new environment by feeding on native forest trees.

Many human diseases have also found their way into the country, with devastating results. The smallpox virus arrived in America with explorers and spread through the susceptible Native American population, killing hundreds of thousands. Syphilis bacteria did the same. Dangerous microbes have also found their way into the country on

HOW SCIENCE WORKS 1.1

Edward Jenner and the Control of Smallpox

Edward Jenner (1749–1823) was born in Berkeley in Gloucestershire in the west of England. As was typical at the time, he became an apprentice to a local doctor and then eventually went to London as a pupil of an eminent surgeon. In 1773, he returned to Berkeley and practiced medicine there for the rest of his life.

At this time in history in Europe and Asia, smallpox was a common disease that nearly everyone developed usually early in life. This resulted in large numbers of deaths, particularly in children. It was known that after infection the person was protected from future smallpox infection. Various cultures had developed ways of reducing the number of deaths caused by smallpox by deliberately infecting people with the smallpox virus. If deliberate infections were given when the patient was otherwise healthy, it was likely that a mild form of the disease would develop and the person would survive and be protected from the disease in the future. In the Middle East, material from the pocks was scratched into the skin. This practice of deliberately infecting people with smallpox was introduced into England in 1717 by Lady Mary Wortley Montagu, the wife of the ambassador to Turkey. She had observed the practice of deliberate infection in Turkey and had her own children inoculated. This practice was common in England in the early 1700s, and Jenner carried out such deliberate inoculations of smallpox as part of his practice. He also frequently came in contact with individuals who had smallpox as well as individuals who were infected with cowpox—a mild disease similar to smallpox.

In 1796, Jenner introduced a safer way to protect against smallpox, which was the result of his 26-year study of these two diseases, cowpox and smallpox. Jenner made two important *observations.* Milkmaids and others who had direct contact with infected cows often developed a mild illness with pocklike sores after milking cows with cowpox sores on their teats. In addition those who had been infected with cowpox rarely became sick with smallpox. He asked the *question,* "Why don't people who have had cowpox get smallpox?" He developed the *hypothesis* that the mild disease caused by cowpox somehow protected them from the often fatal smallpox. This led him to perform an *experiment.* In his first experiment, he took puslike material from a sore on the hand of a milkmaid named Sarah Nelmes and rubbed it into small cuts on the arm of an eight-year-old boy named James Phipps. James developed the normal mild infection typical of cowpox and completely recovered. Subsequently, Jenner inoculated Phipps with material from a person suffering from smallpox. (Recall that this was a normal practice at the time.) James Phipps did not develop any disease. He was protected from smallpox by being purposely exposed to cowpox. The word that was used to describe the process was vaccination. The Latin word for cow is *vacca* and the cowpox disease was known as *vaccinae.*

When these results became known, public reaction was mixed. Some people thought that vaccination was the work of the devil. However, many European rulers supported Jenner by encouraging their subjects to be vaccinated. Napoleon and the Empress of Russia were very influential and, in the United States, Thomas Jefferson had some members of his family vaccinated. Many years later, following the development of the *germ theory of disease,* it was discovered that cowpox and smallpox are caused by viruses that are very similar in structure. Exposure to the cowpox virus allows the body to develop immunity against the cowpox virus and the smallpox virus at the same time. Subsequently, a slightly different virus was used to develop a vaccine against smallpox, which was used worldwide. In 1979, almost 200 years after Jenner developed his vaccination, the Centers for Disease Control and Prevention (CDC) in the United States and the World Health Organization (WHO) of the United Nations declared that smallpox had been eradicated.

The advent of bioterrorism raises awareness about the value of vaccinations. There is a vaccine against anthrax; however, since anthrax is not a communicable disease it is not likely to cause an epidemic. Even though smallpox was eliminated as a disease, the United States and Russia retained samples of smallpox. If terrorists were to obtain samples of the smallpox virus, the virus could be used with deadly effect, because it is contagious. It could easily spread among people of the world, especially those who have not recently been vaccinated.

Today, vaccinations (immunizations) are used to control many diseases that were common during the 1900s. Many of these diseases were known as childhood diseases because essentially all children got them. Today, they are rare in populations that are vaccinated. The following chart shows the schedule of immunizations recommended by the Advisory Committee on Immunization Practices of the American Academy of Pediatrics, and the American Academy of Family Physicians.

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imported research animals. Infected monkeys carried a strain of Ebola virus into the United States. Yet, with these examples to instruct us, there are still people who try to sneak exotic plants and animals into the country without thinking about the possible consequences.

Technological advances and advances in our understanding of human biology have presented us with a series of ethical situations that we have not been able to resolve satisfactorily. Major advances in health care in this generation have prolonged the lives of people who would have died a generation earlier. Many of the techniques and machines that allow us to preserve and extend life are extremely expensive and are therefore unavailable to most citizens of the world. Furthermore, many people in the world lack even the most basic health care, while the rich nations of the world spend money on cosmetic surgery and keep comatose patients alive with the assistance of machines.

Future Directions in Biology

Where do we go from here? Although the science of biology has made major advances, many problems remain to be

HOW SCIENCE WORKS 1.1 *(continued)*

Recommended Childhood Immunization Schedule United States, January–December 2001

AGE / VACCINE	Birth	1 month	2 months	4 months	6 months	12 months	15 months	18 months	24 months	4–6 years	11–12 years	14–18 years
Hepatitis B		First	Second			Third					If any doses missed	
DPT: diphtheria, tetanus, pertussis (whooping cough)			First	Second	Third		Fourth			Fifth	Tetanus and diphtheria	
Haemophilus influenzae type B influenza			First	Second	Third	Fourth						
Injectable inactivated polio			First	Second			Third			Fourth		
Pneumococcal conjugate (pneumonia)			First	Second	Third	Fourth						
MMR: measles, mumps, rubella (German measles)						First				Second	If any doses missed	
Varicella (chickenpox)							First				If first dose missed	2 doses if never had by age 13
Hepatitis A											Children in certain parts of country	

Source: Advisory Committee on Immunization Practices, American Academy of Pediatrics and American Academy of Family Physicians, as appeared in *Morbidity and Mortality Weekly Report,* Center for Disease Control, vol. 43: 51–52, 960, January 6, 1995.

solved. For example, scientists are seeking major advances in the control of the human population and there is a continued interest in the development of more efficient methods of producing food.

One area that will receive much attention in the next few years is the relationship between genetic information and such diseases as Alzheimer's disease, stroke, arthritis, and cancer. These and many other diseases are caused by abnormal body chemistry, which is the result of hereditary characteristics. Curing certain hereditary diseases is a big job. It requires a thorough understanding of genetics and the manipulation of hereditary information in all of the trillions of cells of the organism.

Another area that will receive much attention in the next few years is ecology. Climate change, destruction of natural ecosystems to feed a rapidly increasing human population, and pollution are all still severe problems. Most people need to learn that some environmental changes may be acceptable and that other changes will ultimately lead to our destruction. We have two tasks. The first is to improve technology and increase our understanding about how things work in our biological world. The second, and probably the more difficult, is to educate, pressure, and remind people that their actions determine the kind of world in which the next generation will live.

It is the intent of science to learn what is going on in these situations by gathering the facts in an objective manner. It is also the role of science to identify cause-and-effect relationships and note their predictive value in ways that will improve the environment for all forms of life. Scientists should also make suggestions to politicians and other policymakers about which courses of action are the most logical from a scientific point of view.

SUMMARY

The science of biology is the study of living things and how they interact with their surroundings. Science and nonscience can be distinguished by the kinds of laws and rules that are constructed to unify the body of knowledge. Science involves the continuous testing of rules and principles by the collection of new facts. In science, these rules are usually arrived at by using the scientific method—observation, questioning, exploring resources, hypothesis formation, and the testing of hypotheses. When general patterns are recognized, theories and laws are formulated. If a rule is not testable, or if no rule is used, it is not science. Pseudoscience uses scientific appearances to mislead.

Living things show the characteristics of (1) metabolic processes, (2) generative processes, (3) responsive processes, (4) control processes, and (5) a unique structural organization. Biology has been responsible for major advances in the areas of food production and health. The incorrect application of biological principles has sometimes led to the elimination of useful organisms and to the destruction of organisms we wish to preserve. Many biological advances have led to ethical dilemmas that have not been resolved. In the future, biologists will study many things. Two areas that are certain to receive attention are the relationship between heredity and disease, and ecology.

THINKING CRITICALLY

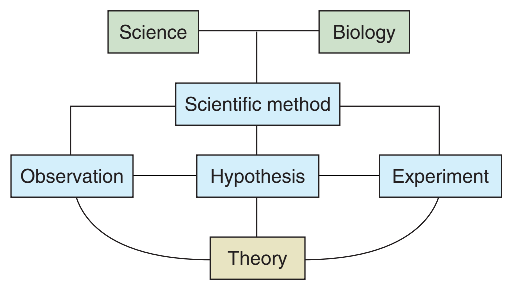
The scientific method is central to all work that a scientist does. Can this method be used in the ordinary activities of life? How might a scientific approach to life change how you choose your clothing or your recreational activities, or which kind of car you buy? Can these choices be analyzed scientifically? Should they be analyzed scientifically? Is there anything wrong with looking at these matters from a scientific point of view?

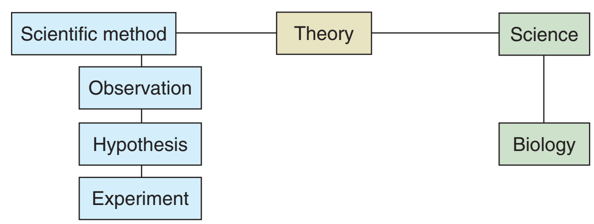
CONCEPT MAP TERMINOLOGY

The construction of a concept map is a technique that helps students recognize how separate concepts are related to one another. Some concept maps may be simple orderly lists. Others may form networks of connections that help to show how ideas are linked. It is important to understand that there is not just one way that things can be put together. The examples show two different ways of looking at the same concepts and organizing them in a meaningful way. (Take another look at figure 1.2. It is a variety of concept map.)

Construct a concept map to show relationships among the following concepts.

biology	observation	scientific method
experiment	science	theory
hypothesis		





KEY TERMS

atom
biology
biosphere
cell
community
control group
control processes
controlled experiment
deductive reasoning (deduction)
dependent variable
ecosystem
empirical evidence
energy
enzymes
experiment
experimental group
generative processes
homeostasis
hypothesis
independent variable
inductive reasoning (induction)
matter
metabolic processes
metabolism
molecule
observation
organ
organ system
organism
population
pseudoscience
reliable
responsive processes
science
scientific law
scientific method
theory
tissue
valid
variable

e—LEARNING CONNECTIONS *www.mhhe.com/enger10*

Topics	Questions	Media Resources
1.1 The Significance of Biology in Your Life	1. List three advances that have occurred as a result of biology. 2. List three mistakes that could have been avoided had we known more about living things.	**Quick Overview** • What has biology done for you? **Key Points** • The significance of biology in your life **Experience This!** • Finding biology in the news
1.2 Science and the Scientific Method	3. List three objects or processes you use daily that are the result of scientific investigation. 4. The scientific method can not be used to deny or prove the existence of God. Why? 5. What are controlled experiments? Why are they necessary to support a hypothesis? 6. List the parts of the scientific method.	**Quick Overview** • What makes science different? **Key Points** • Science and the scientific method
1.3 Science, Nonscience, and Pseudoscience	7. What is the difference between science and nonscience? 8. How can you identify pseudoscience?	**Quick Overview** • Different ways of knowing **Key Points** • Science, nonscience, and pseudoscience **Interactive Concept Map** • Different ways of knowing **Experience This!** • Science or pseuodscience in advertisements
1.4 The Science of Biology	9. What is biology? 10. List five characteristics of living things. 11. What is the difference between regulation and coordination?	**Quick Overview** • How is biology science? **Key Points** • The science of biology **Animations and Reviews** • Life characteristics **Labeling Exercises** • The characteristics of life • Levels of biological organization, Part I • Levels of biological organization, Part II **Interactive Concept Maps** • Text's concept map • Characteristics of life **Review Questions** • What is biology?