1 Learning About Life

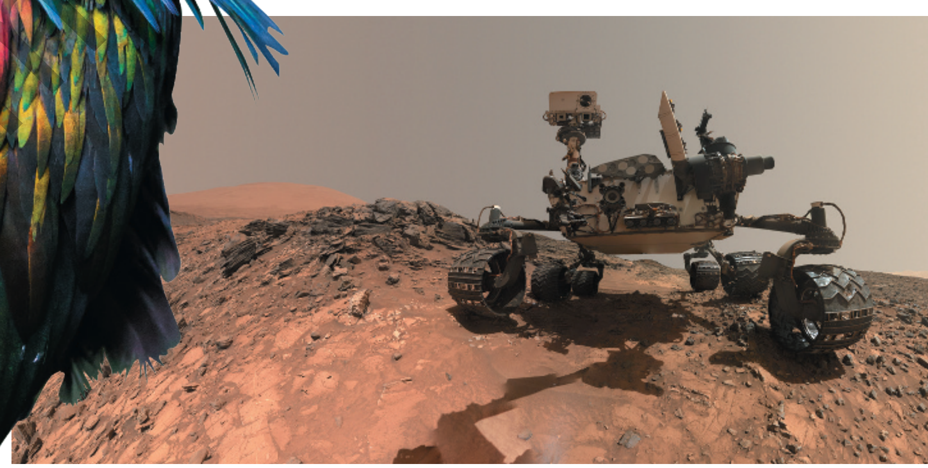
CHAPTER CONTENTS

Why Biology Matters

Nearly everyone has an inborn curiosity about the natural world. Whatever your connection to nature—perhaps you have pets; enjoy visiting parks, zoos, or aquariums; or watch TV shows about interesting creatures—this book will help demonstrate how the study of biology connects to your life.

YOU'RE A SCIENTIST! ALTHOUGH YOU MAY NOT REALIZE IT, YOU USE THE PROCESS OF SCIENCE EVERY DAY.

WHAT THE HECK IS THAT? IF YOU'VE WONDERED WHAT AN UNUSUAL OR ESPECIALLY BEAUTIFUL ANIMAL IS CALLED, YOU'RE CURIOUS ABOUT BIOLOGY.



IS THERE LIFE ON MARS? ONE OF THE MISSIONS OF THE MARS ROVER IS TO SEARCH FOR SIGNS OF LIFE.

CHAPTER THREAD

Swimming with the Turtles

An inborn urge to learn about life. A college student swims with a green sea turtle off the coast of Belize, Central America.

BIOLOGY AND SOCIETY Swimming with the Turtles

A Passion for Life

Imagine yourself floating gently in a warm, calm ocean. Through the blue expanse, you spy a green sea turtle gliding toward you. You watch intently as it grazes on seagrass. It's easy to be captivated by this serene sea creature, with its paddle-shaped flippers and large eyes. As you follow it, you can't help but wonder about its life—how old it is, where it is traveling, whether it has a mate.

It's very human to be curious about the world around us. Nearly all of us have an inherent interest in life, an inborn fascination with the natural world. Do you have a pet? Are you concerned with fitness or healthy eating? Have you ever visited a zoo or an aquarium for fun, taken a nature hike through a forest, grown some plants, or gathered shells on the beach? Would you like to swim with a turtle? If you answered yes to any of these questions, then you share an interest in biology.

We wrote *Essential Biology* to help you harness your innate enthusiasm for life, no matter how much experience you've had with college-level science (even if it's none!). We'll use this passion to help you develop an understanding of the subject of biology, an understanding that you can apply to your own life and to the society in which you live. Whatever your reasons for taking this course—even if only to fulfill your school's science requirement—you'll soon discover that exploring life is relevant and important to you.

To reinforce the fact that biology does indeed affect you personally, every chapter of *Essential Biology* opens with an essay—called Biology and Society—where you will see the relevance of that chapter's material. Topics as varied as green energy (Chapter 7), pet genetics (Chapter 9), and the importance of biodiversity (Chapter 20) help to illustrate biology's scope and show how the subject of biology is woven into the fabric of society. Throughout *Essential Biology*, we'll continuously emphasize these connections, pointing out many examples of how each topic can be applied to your life and the lives of those you care about.

The Scientific Study of Life

Now that we've established our goal—to examine how biology affects your life—a good place to start is with a basic definition: **Biology** is the scientific study of life. But have you ever looked up a word in the dictionary, only to find that you need to look up some of the words within that definition to make sense of the original word? The definition of *biology*, although seemingly simple, raises questions such as "What is a scientific study?" and "What does it mean to be alive?"

IF YOU'VE WONDERED WHAT AN UNUSUAL OR ESPECIALLY BEAUTIFUL ANIMAL IS CALLED, YOU'RE CURIOUS ABOUT BIOLOGY.

To start your investigation, this first chapter of *Essential Biology* will explain important concepts within the definition of biology. First, we'll place the study of life in the broader context of science. Next, we'll investigate the nature of life. Finally, we'll introduce a series of broad themes that serve as organizing principles for the information you will learn. Most importantly, throughout this chapter (and all of *Essential Biology*), you'll see examples of how biology affects *your* life, highlighting the relevance of this subject to society and everyone in it. ✅

✅ **CHECKPOINT**

Define biology.

■ Answer: Biology is the scientific study of life.

An Overview of the Process of Science

The definition of *biology* as the scientific study of life leads to an obvious first question: What does it mean to study something scientifically? Notice that biology is not defined simply as "the study of life" because there are many nonscientific ways that life can be studied. For example, meditation is a valid way of contemplating life, but it is not a *scientific* means of studying life, and therefore it does not fall within the scope of biology. How, then, do we tell the difference between science and other ways of trying to make sense of the world?

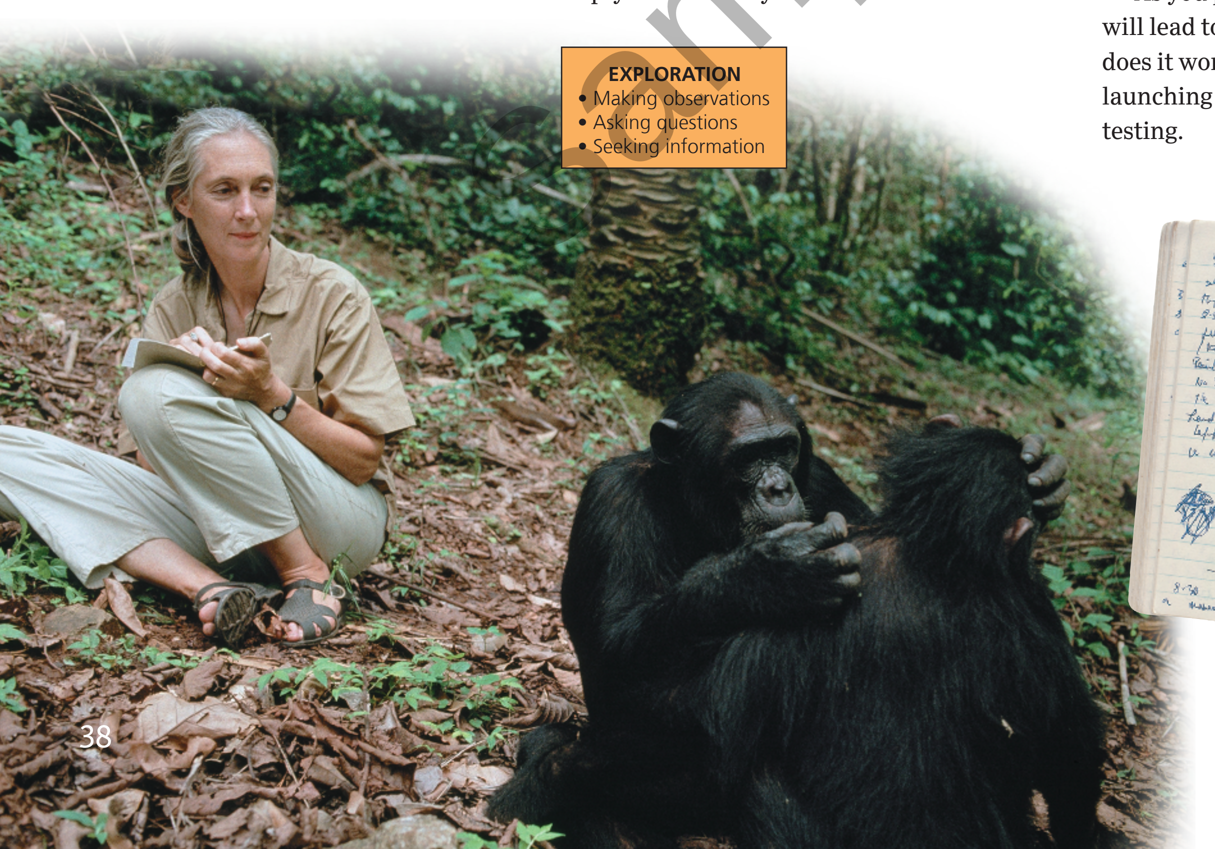
Science is an approach to understanding the natural world that is based on inquiry—a search for information, evidence, explanations, and answers to specific questions. Scientists seek natural causes for natural phenomena. Therefore, they focus solely on the study of structures and processes that can be verifiably observed and measured.

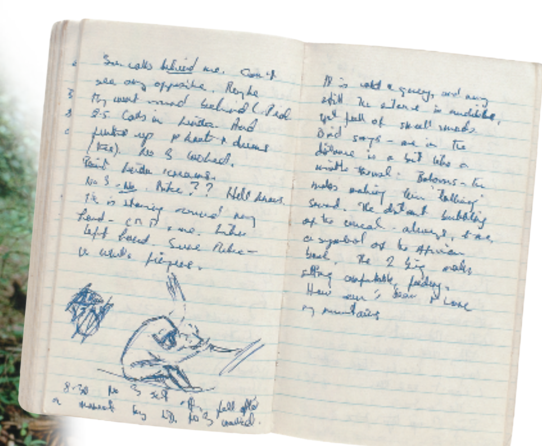
Exploration

If you wanted to understand something—say, the behavior of a sea turtle—how would you start? You'd probably begin by looking at it. Biology, like other sciences, begins with exploration **(Figure 1.1)**. During this initial phase of inquiry, you may simply watch the subject and record your observations. A more intense exploration may involve extending your senses using tools such as microscopes or precision instruments to allow for careful measurement. Whatever the source, recorded observations are called **data**—the evidence on which scientific inquiry is based. In addition to gathering your own data, you may read books or articles on the subject to learn about previously collected data.

As you proceed with your exploration, your curiosity will lead to questions, such as "Why is it this way?" "How does it work?" "Can I change it?" Such questions are the launching point for the next step in the process of science: testing.

▼ **Figure 1.1 Scientific exploration.** Dr. Jane Goodall spent decades recording her observations of chimpanzee behavior during field research in the jungles of Tanzania.



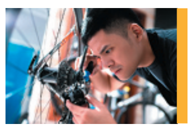


Testing

After making observations and asking questions, you may wish to conduct tests. But where do you start? You could probably think of many possible ways to investigate your subject. But you can't possibly test them all at once. To organize your thinking, you will likely begin by selecting one possible explanation and testing it. In other words, you would make a hypothesis. A **hypothesis** is a proposed explanation for a set of observations. A valid hypothesis must be testable and falsifiable—that is, it must be capable of being demonstrated to be false. A good hypothesis thus immediately leads to predictions that can be tested. Some hypotheses (such as ones involving conditions that can be easily controlled) lend themselves to **experiments**, or scientific tests. Other hypotheses (such as ones involving aspects of the world that cannot be controlled, such as ecological issues) can be tested by making further observations. The results of an experiment will either support or not support the hypothesis.

We all use hypotheses in solving everyday problems, although we don't think of it in those terms. Imagine that you press the power button on your TV remote, but the TV fails to turn on. That the TV does not turn on is an observation. The question that arises is obvious: Why didn't the remote turn on the TV? You probably would not just throw your hands up in the air and say "There's just no way to figure this out!" Instead, you might imagine several possible explanations, but you couldn't investigate them all simultaneously. Instead, you would focus on just one explanation, perhaps the most likely one based on past experience, and test it. That initial explanation is your hypothesis. For example, in this case, a reasonable hypothesis is that the batteries in the remote are dead.

After you've formed a hypothesis, you would make further observations or conduct experiments to investigate this initial idea. In this case, you can predict that if you replace the batteries, the TV will work. Let's say that you conduct this experiment, and the remote still doesn't work. You conclude that this observation does not support your hypothesis. You would then formulate a second hypothesis and test it. Perhaps you hypothesize that the TV is unplugged. You could continue to conduct additional experiments and formulate additional hypotheses until you reach a satisfactory answer to your initial question. As you do this, you are following a series of steps that provide a loose guideline for scientific investigations. These steps are shown in **Figure 1.2** and are sometimes called "the scientific method." They are a rough "recipe" for discovering new explanations, a set of procedures that, if followed, may provide insight into the subject at hand.



ALTHOUGH YOU MAY NOT REALIZE IT, YOU USE THE PROCESS OF SCIENCE EVERY DAY.

The steps are simply a way of formalizing how we usually try to solve problems. If you pay attention, you'll find that you often formulate hypotheses, test them, and draw conclusions. In other words, the process of science is probably your "go-to" method for solving problems. Although the process of science is often presented as a series of linear steps (such as those in Figure 1.2), in reality investigations are almost never this rigid. Different questions will require different paths through the steps. There is no single formula for successfully discovering something new; instead, the process of science suggests a broad outline for how an investigation might proceed. ✓

✓ CHECKPOINT

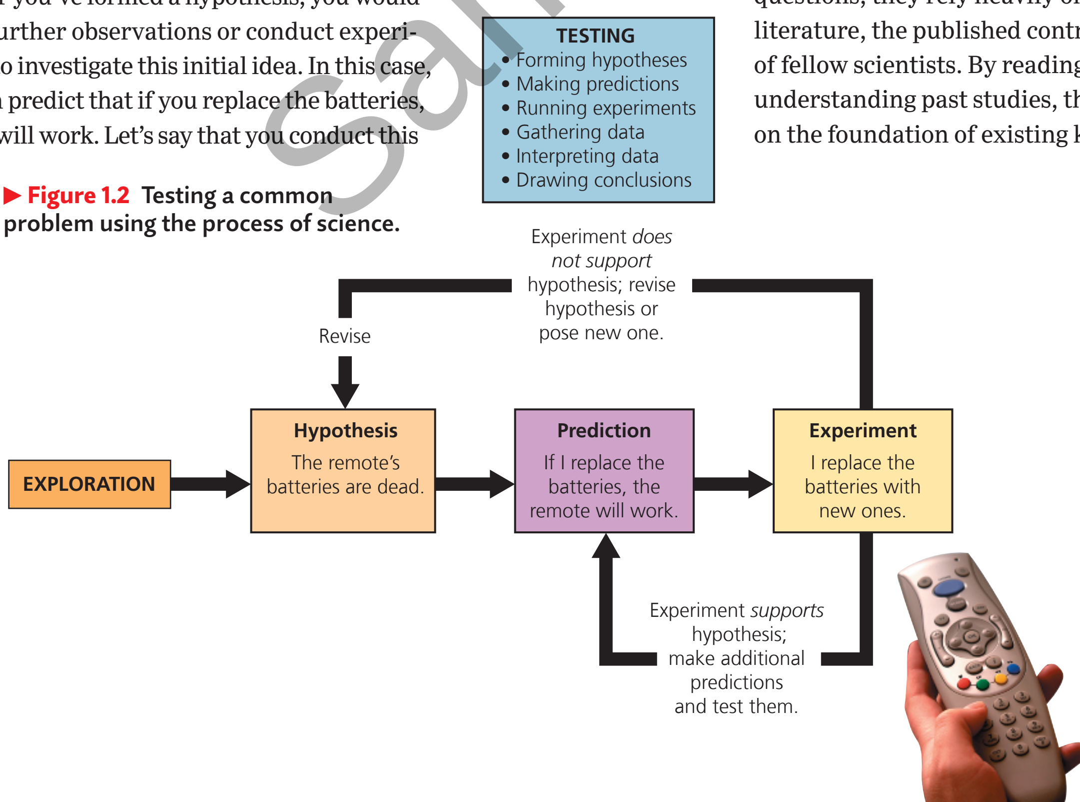
Do all scientific investigations follow the steps in Figure 1.2 in that precise order? Explain.

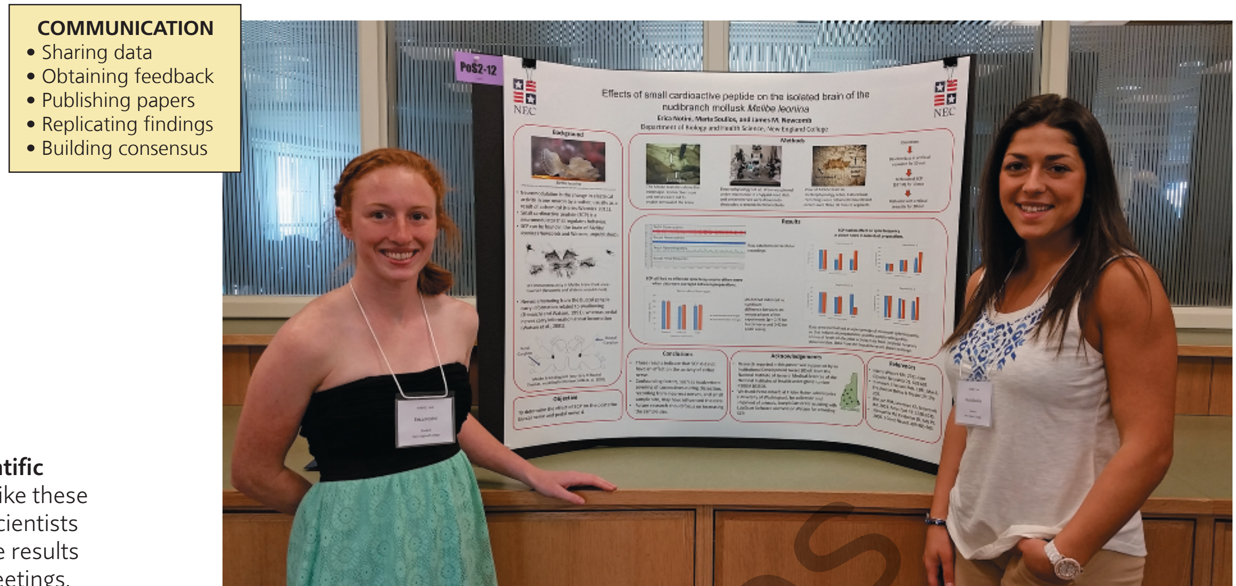
■ *Answer: No. Different scientific investigations may proceed through the process of science in different ways.*

Communication and Outcomes

The process of science is typically repetitive and nonlinear. For example, scientists often work through several rounds of making observations and asking questions, with each round informing the next, before settling on hypotheses that they wish to test. In fine-tuning their questions, they rely heavily on scientific literature, the published contributions of fellow scientists. By reading about and understanding past studies, they can build on the foundation of existing knowledge.

▶ **Figure 1.2 Testing a common problem using the process of science.**





▶ Figure 1.3 Scientific communication. Like these college students, scientists often communicate results to colleagues at meetings.

Additionally, scientists communicate with each other through seminars, meetings, personal communication, and scientific publications **(Figure 1.3)**. Before experimental results are published in a scientific journal, the research is evaluated by qualified, impartial, often anonymous experts who were not involved in the study. This process, intended to provide quality control, is called **peer review**. Reviewers often require authors to revise their paper or perform additional experiments in order to provide more lines of evidence. It is not uncommon for a scientific journal to reject a paper entirely if it doesn't meet the rigorous standards set by fellow scientists. After a study is published, scientists often check each other's claims by attempting to confirm observations or repeat experiments.

Science does not exist just for its own sake. In fact, it is interwoven with the fabric of society **(Figure 1.4)**. Much of scientific research is focused on solving problems that influence our quality of life, such as the push to cure cancer or to understand and slow the process of climate change. Societal needs often determine which research projects are funded. Scientific studies may involve basic research (largely concerned with building knowledge) or they may be more applied (largely concerned with developing new technologies). The ultimate aim of most scientific investigations is to benefit society. This focus on outcomes highlights the connections between biology, your own life, and our larger society.

▶ Figure 1.4 Scientific outcomes. A 22-year-old woman tries on her new prosthetic hand with individually movable bionic fingers.

Putting all these steps together, **Figure 1.5** presents a more comprehensive model of the process of science. You can see that forming and testing hypotheses (represented in blue) are at the center of science. This core set of activities is the reason that science explains natural phenomena so well. These activities, however, are shaped by exploration (orange) and influenced by communication with other scientists (yellow) and by outcomes (green). Notice that many of these activities connect to others, illustrating that the components of the process of science interact. As in all quests, science includes elements of challenge, adventure, and luck, along with careful planning, reasoning, creativity, patience, and persistence in overcoming setbacks. Such diverse elements of inquiry allow the process of science to be flexible, molded by the needs of each particular challenge.

In every chapter of *Essential Biology*, we include examples of how the process of science was used to study the content presented in that chapter. Some of the questions that will be addressed are Do baby turtles swim (this chapter)? Can avatars improve cancer treatment (Chapter 11)? What can lice teach us about ancient humans (Chapter 17)?

As you become increasingly scientifically literate, you will arm yourself with the tools you need to evaluate claims that you hear. We are all bombarded by information every day—through commercials, social media, websites, magazine articles, and so on—and it can be hard to filter out the bogus from the truly worthwhile. Having a firm grasp of science as a process of inquiry can therefore help you in many ways outside the classroom. ✓

▼ Figure 1.5 An overview of the process of science. Notice that performing scientific tests lies at the heart of the entire process.

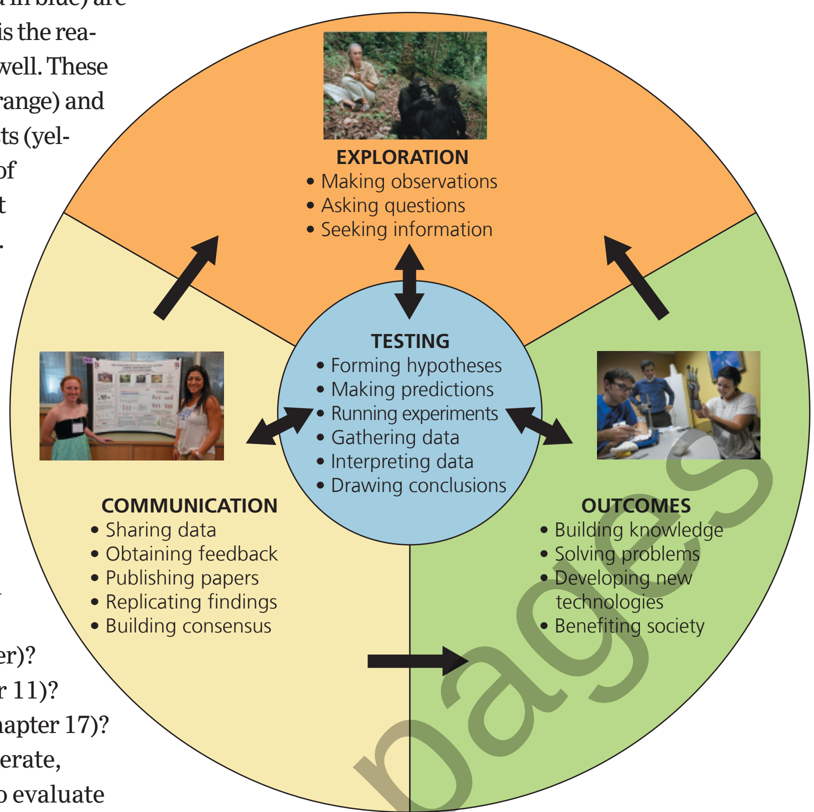


Figure Walkthrough
Mastering Biology
goo.gl/6bRdg9

Hypotheses, Theories, and Facts

Since scientists focus on natural phenomena that can be reliably observed and measured, let's explore how the terms *hypothesis, theory,* and *fact* are related.

As previously noted, a hypothesis is a proposed explanation for an observation. In contrast, a scientific **theory** is much broader in scope than a hypothesis. A theory is a comprehensive and well-substantiated explanation. Theories only become widely accepted by scientists if they are supported by a large, varied, and growing body of evidence. A theory can be used to explain many observations. Indeed, theories can be used to devise many new and testable hypotheses. It is important to note that scientists use the word *theory* differently than many people tend to use it in everyday speech, which implies untested speculation ("It's just a theory!"). In fact, the word *theory* is commonly used in everyday speech in the way a scientist uses the word *hypothesis*. It is therefore improper to say that a scientific theory, such as the theory of evolution, is "just" a theory to imply that it is untested or lacking in evidence. In reality, every scientific theory is backed up by a wealth of supporting evidence, or else it wouldn't be referred to as a theory. However, a theory, like any scientific idea, must be refined or even abandoned if new, contradictory evidence is discovered.

A **fact** is a piece of information considered to be objectively true based on all current evidence. A fact can be verified and is therefore distinct from opinions (beliefs that can vary from person to person), matters of taste, speculation, or inference. However, science is self-correcting: New evidence may lead to reconsideration of information previously regarded as a fact.

Many people associate facts with science, but accumulating facts is not the primary goal of science. A dictionary is an impressive catalog of facts, but it has little to do with science. It is true that facts, in the form of verifiable observations and repeatable experimental results, are the prerequisites of science. What advances science, however, are new theories that tie together a number of observations that previously seemed unrelated. The cornerstones of science are the explanations that apply to the greatest variety of phenomena. People like Isaac Newton, Charles Darwin, and Albert Einstein stand out in the history of science not because they discovered a great many facts but because their theories had such broad explanatory power. ✓

✓ CHECKPOINT

Why does peer review improve the reliability of a scientific paper?

Answer: A peer-reviewed paper carries a "seal of approval" from impartial experts on the subject.

✓ CHECKPOINT

You arrange to meet a friend for dinner at 6 P.M., but when the appointed hour comes, she is not there. You wonder why. Another friend says, "My theory is that she forgot." If your friend were speaking like a scientist, what would she have said?

Answer: "My hypothesis is that she forgot."

Controlled Experiments

To investigate a hypothesis, a researcher often runs a test multiple times with one factor changing and, ideally, all other factors of the test being held constant. **Variables** are factors that change in an experiment. Most well-designed experiments involve the researcher changing just one variable at a time, with all other aspects held the same.

A **controlled experiment** is one that compares two or more groups that differ only in one variable that the experiment is designed to test. The **control group** lacks or does not receive the specific factor being tested. The **experimental group** has or receives the specific factor being tested. The use of a controlled experiment allows a scientist to draw conclusions about the effect of the one variable that did change. For example, you might compare cookie recipes by altering the amount of butter (the variable in this experiment) while keeping all other ingredients the same. In this case, the original cookie recipe is the control group, while the new recipe with more butter is the experimental group. If you were to vary both the butter and the flour at the same time, it would be difficult to know which variable was responsible for any changes in the cookies. To further illustrate this principle, let's look at a controlled experiment that investigated whether baby sea turtles swim or just drift in the water.

THE PROCESS OF SCIENCE | Swimming with the Turtles

Do Baby Turtles Swim?

BACKGROUND

If you've spent time on the beach during the summer, you may have seen signs about endangered sea turtles, warning people to leave beach nests alone and to turn off lights in the evening. This is because, after emerging from a 2-month incubation, turtle hatchlings dig their way out of the sand and then use moonlight to navigate to the sea (Figure 1.6a). What happens next has long been a mystery to marine biologists. Can the juvenile turtles swim in ocean currents? Or do they just passively drift? No one knows how baby sea turtles travel during their first several years. In fact, some marine biologists refer to this time as "lost years" in the turtle life cycle.

METHOD

In 2015, researchers from the University of Central Florida investigated the question of whether baby green sea turtles swim or drift. They attached tiny satellite trackers to 24 green sea turtles, each between 1 and 2 years old, in the Gulf of Mexico (Figure 1.6b). The researchers also attached trackers to floating buckets and released them at the same time and in the same locations. The experiment was conducted under a scientific research permit from the National Marine Fisheries Service (NMFS).

RESULTS

Including a control group (the floating buckets) allowed the researchers to draw conclusions about the experimental group (the baby turtles). Comparing data on the paths taken by each group revealed that the turtles moved slowly (averaging only 0.4 miles per hour). However, the turtles moved faster and along different tracks than the floating buckets (Figure 1.6c). These data suggest that, despite longstanding assumptions by marine biologists, very young sea turtles travel by swimming, and not just drifting. Such information may help efforts to protect endangered species of sea turtles.

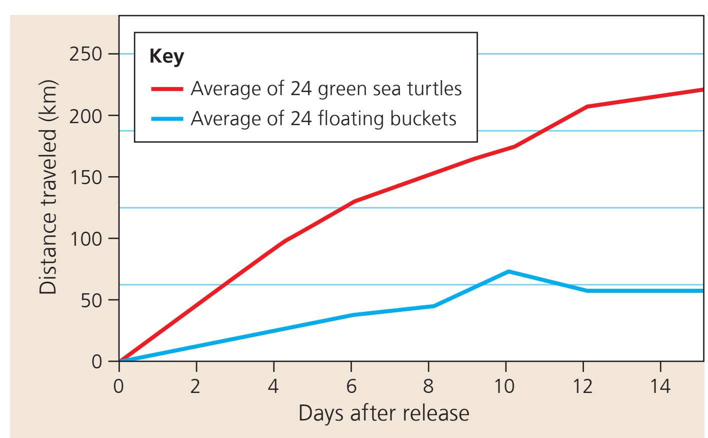
Thinking Like a Scientist
What was the purpose of attaching transmitters to floating buckets?
For the answer, see Appendix D.

▼ **Figure 1.6 Tracking baby sea turtles.**

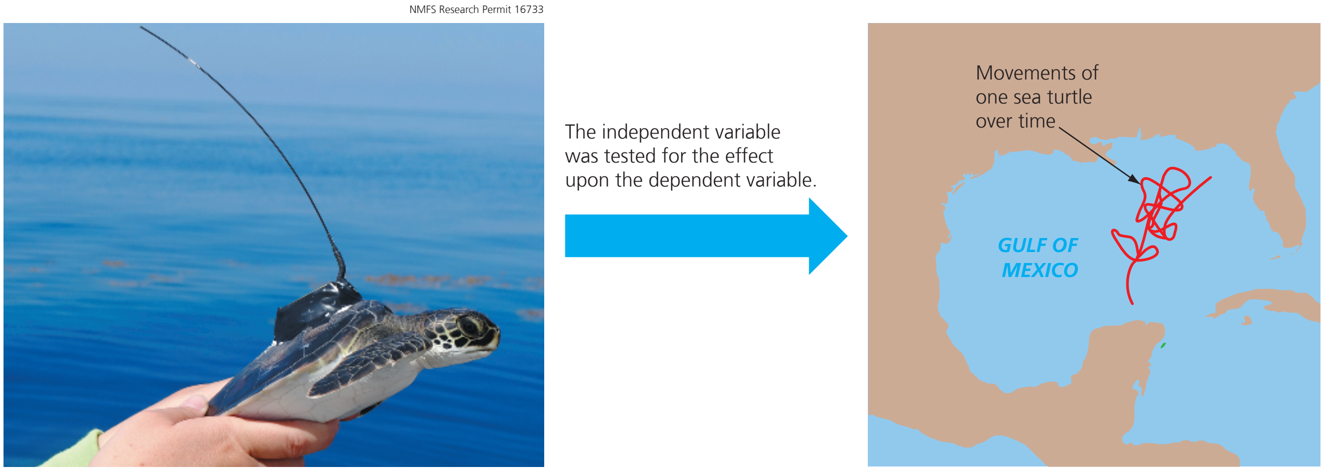
(a) Green sea turtle hatchlings scrambling to the sea

NMFS Research Permit 16733

(b) Satellite tracker on the back of a baby turtle



(c) Graph showing the distance traveled by the average turtle (red line) versus the average floating bucket (blue line)



In this experiment, the independent variable (what is being changed) was the type of object being tracked: the sea turtles or the floating buckets.

In this experiment, the dependent variable (the effect under investigation) was the speed of travel.

◀ **Figure 1.7 Independent versus dependent variables.** These hypothetical data on green sea turtle migration show the relationship between these two types of variables.

The study on whether baby sea turtles swim is a good example of a controlled experiment. The variable was the identity of the object followed: turtles versus buckets. Other factors in the experiment—such as the type of satellite tracker used, when and where they were released, how often data were collected, and how speed was calculated—were purposefully kept the same. The control group was the floating buckets, and the experimental group was the baby sea turtles. The buckets were the control group because they lacked the factor being tested: the ability to move on their own. By comparing the movements of the floating buckets with the movements of the baby sea turtles, the experimenters could be confident that any observed differences were due to the turtles being able to swim.

In a controlled experiment, like the one just described, the **independent variable** is what is being manipulated by the researchers as a potential cause—in this case, the object under investigation (either turtles or buckets). The **dependent variable** is the response, output, or effect under investigation that is used to judge the outcome of the experiment—in this case, the speed of movement. The dependent (measured) variable is affected by the independent (manipulated) variable **(Figure 1.7)**. Well-designed experiments often test just one independent variable at a time.

A controlled experiment can sometimes be a blind experiment, in which some information about the experiment is withheld from participants **(Figure 1.8)**. For example, the turtle researchers may have analyzed the trajectory data without knowing whether each track was a turtle or a bucket. The identities of the blinded components are revealed only after the experiment is complete. Performing the study blind removes bias on the part of the investigators. This type of study is called a **single-blind experiment**.

Many medical drug trials include a **placebo**, a medically ineffective treatment that allows the placebo group to serve as a control group. Typically, the placebo group does not know that they are receiving an ineffective substitute. An experiment in which neither the participant nor the experimenter knows which group is the control group is called a **double-blind experiment**. The "gold standard" for a medical trial is a "double-blind placebo-controlled study," meaning that neither the patients nor the doctors know which patients received the real treatment and which received a placebo. Such a design prevents bias on the part of the researchers and also takes into account the placebo effect, a well-documented phenomenon whereby giving patients a fake treatment nonetheless causes them to improve due to their belief that they are receiving an effective treatment. ✅

✅ **CHECKPOINT**

You bake two recipes of cookies and label them "A" and "B." You ask a group of friends to rate the recipes. Design a double-blind experiment to determine which recipe is superior.

■ *Answer: A third party should label the cookies and collect the data so that neither the investigator (you) nor the subjects (your friends) know which recipe is which.*

Evaluating Scientific Claims

The process of science involves evaluating scientific claims. Sometimes claims are made using scientific jargon with the intention of appearing to conform to scientific standards without actually doing so. **Pseudoscience** is any field of study that is falsely presented as having a scientific basis. Given our access to huge amounts of information, much of it unreliable, the ability to recognize pseudoscience is a very important thinking skill. Although the difference between valid science and pseudoscience can at times

▼ **Figure 1.8 How to recognize blind studies.**

TYPE OF STUDY	TEST SUBJECTS KNOW WHICH GROUP IS WHICH?	RESEARCHERS KNOW WHICH GROUP IS WHICH?
Not blind	Yes	Yes
Single blind	No	Yes
Double blind	No	No

A field biologist collecting data

FEATURES OF SCIENCE	FEATURES OF PSEUDOSCIENCE
Adheres to an established and well-recognized scientific method	Does not adhere to generally accepted processes of science
Repeatable results	Results that cannot be duplicated by others; results that rely on a single person or are solely opinion
Testable claims that can be disproven	Unprovable or untestable claims; reliance on assumptions or beliefs that are not testable
Open to outside review	Rejection of external review or refusal to accept contradictory evidence
Multiple lines of evidence	Overreliance on a small amount of data; underlying causes are not investigated

A pyramid that is claimed to channel energy

▶ **Figure 1.9 Features of science versus pseudoscience.**

be confusing, there are several indicators that you can use to recognize pseudoscience **(Figure 1.9)**. For example, a pseudoscientific study may be based soley or largely on **anecdotal evidence**, an assertion based on a single or a few examples that do not support a generalized conclusion—for example, "Today was unusually cold, so global warming must be a hoax!" A proper scientific investigation is open to outside review (the communication step in Figure 1.5), while pseudoscientific claims often reject external review or refuse to accept contradictory evidence. Often, pseudoscientific claims are based on results that cannot be duplicated by others because they rely on a single person or are solely opinion. A proper scientific study, on the other hand, has repeatable results that stand up to external scrutiny.

One of the best ways to evaluate scientific claims is to consider the source of the information **(Figure 1.10)**. Science depends upon peer review, the evaluation of work by impartial, qualified, often anonymous experts who are not involved in that work. Publishing a study in a peer-reviewed journal is often the best way to ensure that it will be considered scientifically valid. No matter the source, reliable scientific information can be recognized by being up to date, drawing from known sources of information, having been authored by a reputable expert, and being free of bias.

Now that we have explored the process of science, keep in mind that it has proven to be the most effective method for investigating the natural world. In fact, nearly everything we know about nature was learned through the process of science. ✓

▼ **Figure 1.10 Recognizing a reliable source.** The more criteria a given source meets, the more reliable it is.

Souce reliability checklist

- ☐ Is the information current?
- ☐ Is the source primary (and not secondary)?
- ☐ Is/are the author(s) indentifiable and well qualified?
- ☐ Does the author lack potential conflicts of interest?
- ☐ Are references cited?
- ☐ Are any experiments described in enough detail that they could be reproduced?
- ☐ Was the information peer reviewed?
- ☐ Is the information unbiased?
- ☐ Is the intent of the source known and valid?

✓ CHECKPOINT

If someone says, "It rained yesterday, so I don't believe that there is a drought," this is an example of what kind of improper thinking?

■ Answer: a conclusion based on anecdotal evidence

The Properties of Life

Recall once again the definition at the heart of this chapter: Biology is the scientific study of life. Now that we understand what constitutes a scientific study, we can turn to the next question raised by this definition: What is life? Or, to put it another way, what distinguishes living things from nonliving things? The phenomenon of life seems to defy a simple, one-sentence definition. Yet even a small child instinctively knows that a bug or a plant is alive but a rock is not.

If someone placed an object in front of you and asked whether it was alive, what would you do? Would you poke it to see if it reacts? Would you watch it closely to see if it moves or breathes? Would you dissect it to look at its parts? Each of these ideas is closely related to how biologists actually define life: We recognize life mainly by what living things do. Using a green sea turtle as an example, **Figure 1.11** highlights the major properties we associate with life: order, cells, growth and development, energy processing, regulation, response to the environment, reproduction, and evolution.

An object is generally considered to be alive if it displays all of these characteristics simultaneously. On the other hand, a nonliving object may display some of these properties, but not all of them. For example, a virus has an ordered structure, but it cannot process energy, nor is it composed of cells. Viruses, therefore, are generally not considered to be living organisms (see Chapter 10 for more information on viruses).

▼ **Figure 1.11 A green sea turtle displays the properties of life.**
An object is considered alive only if it displays all of these properties simultaneously.

Order is apparent in many of the turtle's structures, such as the regular arrangement of plates in the turtle shell.

Like any large organism, the body of a sea turtle is made of trillions of **cells**.

Growth and development into a mature adult sea turtle takes decades.

Scientists who study turtle **evolution** believe that they first appeared nearly 250 million years ago, making their lineage older than the dinosaurs.

As part of the turtle **reproduction** cycle, a female will lay 100-200 eggs into a hole dug in a sandy beach.

The sex of sea turtle hatchlings varies in **response to the environment:** Warmer temperatures favor the development of females, while cooler temperatures favor the development of males.

Energy processing in adult sea turtles depends upon a diet of algae and sea grass.

Although surrounded by salt water, sea turtles carry out **regulation** of the salt level in their body by excreting excess salt through their eyes.

▼ **Figure 1.12 A sample of the diversity of life in a national park in Namibia.**

Even as life on Earth shares recognizable properties, it also exists in tremendous diversity (Figure 1.12; see also Chapters 13–17). But must we limit our discussion to life on this planet? Although we have no proof that life has ever existed anywhere other than Earth, biologists speculate that extraterrestrial life, if it exists, could be recognized by the same properties described in Figure 1.11. The Mars rover *Curiosity*, which has been exploring the surface of the red planet since 2012, contains several instruments designed to identify substances that provide evidence of past or present life. For example, *Curiosity* is using a suite of onboard instruments to detect chemicals that could provide evidence of energy processing by microscopic organisms. In 2017, NASA announced that one of Saturn's moons, Enceladus, is the most likely place in our solar system to find extraterrestrial life, due to its abundant water and geothermal activity. NASA hopes to launch a probe there soon. The search continues. ✓

ONE OF THE MISSIONS OF THE MARS ROVER IS TO SEARCH FOR SIGNS OF LIFE.

✓ **CHECKPOINT**

Which properties of life apply to a car? Which do not?

■ *Answer: A car demonstrates order, regulation, energy processing, and response to the environment. But a car does not grow, reproduce, or evolve, and it is not composed of cells.*

Major Themes in Biology

As new discoveries unfold, biology grows in breadth and depth. However, major themes continue to run throughout the subject. These overarching principles unify all aspects of biology, from the microscopic world of cells to the global environment. Focusing on a few big-picture ideas that cut across many topics within biology can help organize and make sense of all the information you will learn.

This section describes five unifying themes that recur throughout our investigation of biology: the relationship of structure to function, information flow, pathways that transform energy and matter, interactions within biological systems, and evolution. You'll encounter these themes throughout subsequent chapters, with some key examples **highlighted in blue in the text**.

The Relationship of Structure to Function

When considering useful objects in your home, you may realize that form and function are related. A chair, for example, cannot have just any shape; it must have a stable base to hold it up and a flat area to support weight. The function of the chair constrains the possible shapes it may have. Similarly, within biological systems, structure (the shape of something) and function (what it does) are often related, with each providing insight into the other.

The correlation of structure and function can be seen at different levels, or scales, within biological systems, such as molecules, cells, tissues, and organs. Consider your lungs, which function to exchange gases with the environment: Your lungs bring in oxygen (O_2) and take out carbon dioxide (CO_2). The structure of your lungs correlates with this function **(Figure 1.13)**. The smallest branches of your lungs end in millions of tiny sacs in which the gases cross from the air to your blood, and vice versa. This branched structure (the form of the lungs) provides a tremendous surface area over which a very high volume of air may pass (the function of the lungs). At quite another level, the correlation of structure and function can be seen in your cells. For example, oxygen diffuses into red blood cells as it enters the blood in the lungs. The indentations of red blood cells **(Figure 1.14)** increase the surface area through which oxygen can diffuse; without such indentations, there would be less surface area through which gases could move.

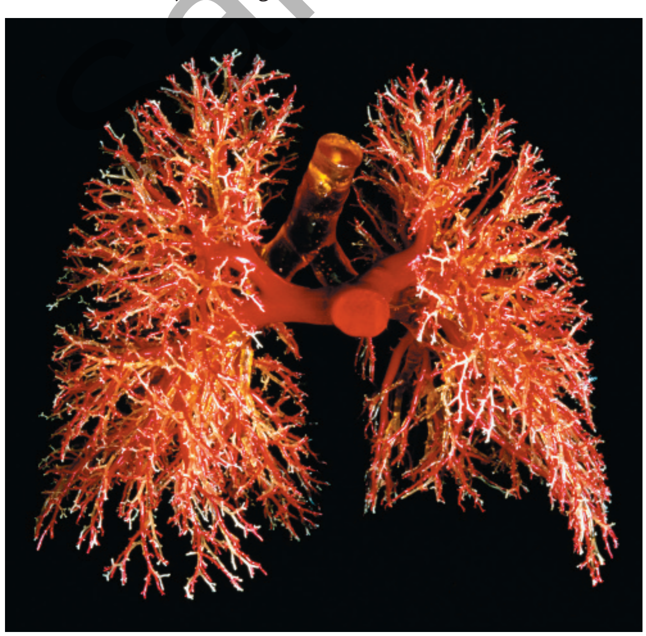
Throughout your study of life, you will see the structure and function principle apply to all levels of biological organization, such as the structures of molecules and of entire organisms. Some specific examples of the correlation of structure and function include the relationship between a misshapen protein and a deadly brain disease (Chapter 3), how the structure of DNA allows it to act as the molecule of heredity (Chapter 10) and to serve as the basis of forensic investigations (Chapter 12), and structural adaptations within the bodies of plants (Chapter 16). ✓

✓ CHECKPOINT

Explain how the correlation of structure to function applies to a tennis racket.

■ *Answer: A tennis racket must have a large, flat surface for striking the ball, an open mesh so that air can flow through, and a handle for grasping and controlling the racket.*

▼ **Figure 1.13 Structure and function: human lungs.** The structure of your lungs correlates with their function.



▼ **Figure 1.14 Structure and function: red blood cells.** As oxygen enters the blood in the lungs, it diffuses into red blood cells.

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Information Flow

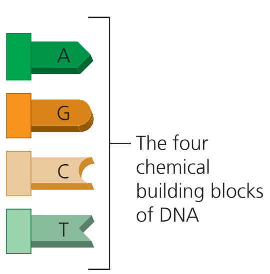
For life's functions to proceed in an orderly manner, information must be received, transmitted, and used. Just as our society depends upon communication between its members, a "society" of biological components cannot function as a living system without the flow of information. Such information flow is apparent at all levels of biological organization. For example, information about the amount of glucose in the bloodstream is received by organs such as your pancreas. The pancreas acts on that information by releasing hormones (including insulin) that regulate the levels of glucose in the blood. As insulin takes effect and glucose levels change, the pancreas processes this information, making continuous adjustments.

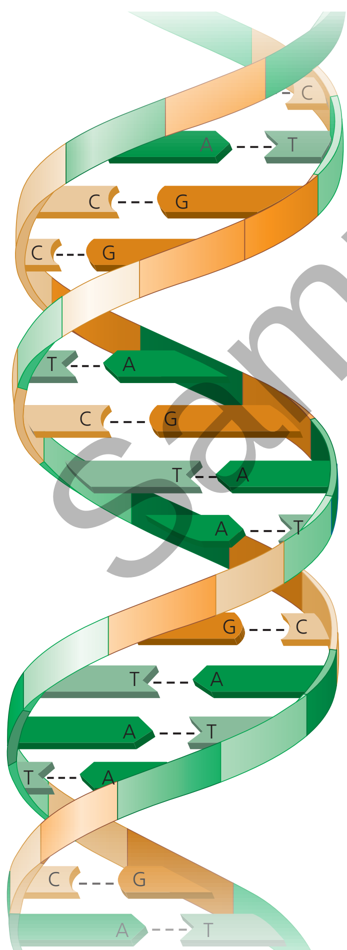
At the microscopic level, every cell contains **genes**, hereditary units of information consisting of specific sequences of DNA passed on from the previous generation. At the organismal level, as every multicellular organism develops from an embryo, information exchanged between cells enables the overall body plan to take shape in an organized fashion (as you'll see in Chapter 11). When the organism is mature, information about the internal conditions of its body is used to keep those conditions within a range that allows for life. Although bacteria and humans inherit different genes, that information is encoded in an identical chemical language common to all organisms. In fact, the language of life has an alphabet of just four letters. The chemical names of DNA's four molecular building blocks are abbreviated as A, G, C, and T **(Figure 1.15)**. A typical gene is hundreds to thousands of chemical "letters" in length. A gene's meaning to a cell is encoded in its specific sequence of these letters, just as the message of this sentence is encoded in its arrangement of the 26 letters of the English alphabet.

How is all this information used within your body? At any given moment, your genes are coding for the production of thousands of different proteins that control your body's processes. (You'll learn the details of how proteins are produced using information from DNA in Chapter 10.) Food is broken down, new body tissues are built, cells divide, signals are sent—all controlled by information stored in your DNA. For example, information in one of your genes translates to "Make insulin," helping your body regulate blood sugar.

People with type 1 diabetes often have a mutation (error) in a different gene that causes the body's immune cells to attack and destroy the insulin-producing pancreas cells. These cells are then unable to properly respond to information about glucose levels in the blood. The breakdown of the normal flow of information within the body leads to disease. Some people with diabetes regulate their sugar levels by injecting themselves with insulin **(Figure 1.16)** produced by genetically engineered bacteria. These bacteria can make insulin because the human gene has been transplanted into them. ✓

▶ Figure 1.15 Information stored in DNA. Every molecule of DNA is constructed from four kinds of chemical building blocks that are chained together, shown here as simple shapes and letters. Genetic information is encoded in the sequence of these building blocks.





▼ Figure 1.16 Information flow and diabetes. In some people with diabetes, a mutation causes a disruption in the normal flow of genetic information. For such people, insulin produced by genetically engineered bacteria can be lifesaving.

Pathways That Transform Energy and Matter

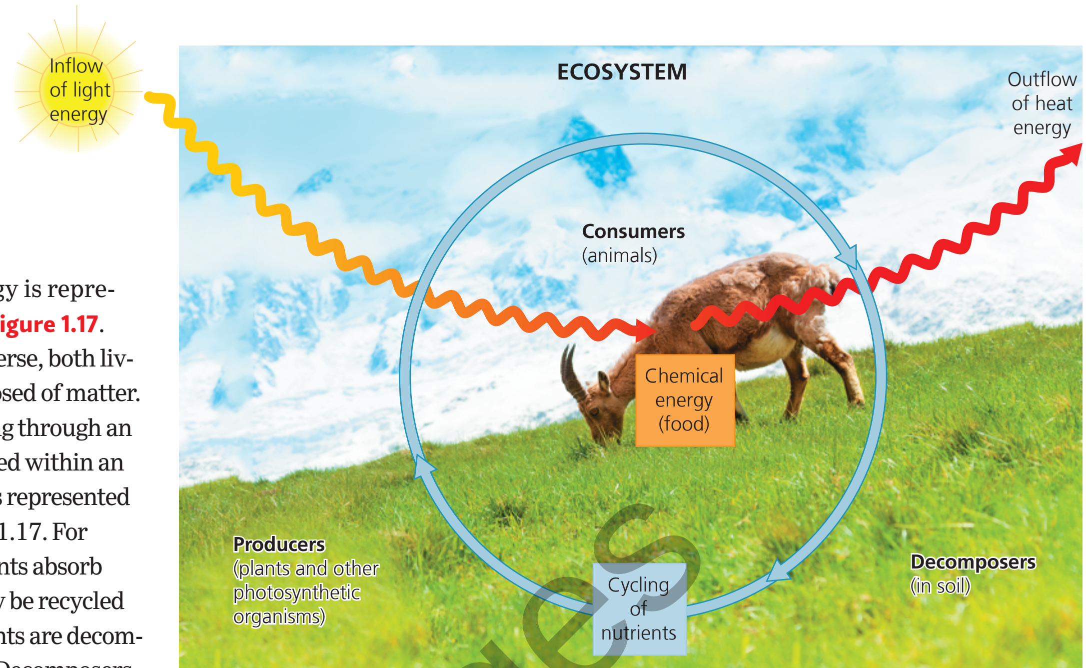
Movement, growth, reproduction, and the various cellular activities of life are work, and work requires energy. The input of energy, primarily from the sun, and the transformation of energy from one form to another make life possible. Most ecosystems are solar powered at their source. The energy that enters an ecosystem as sunlight is captured by plants and other photosynthetic organisms (producers) that absorb the sun's energy and convert it into chemical energy, storing it as chemical bonds within sugars and other complex molecules. Food molecules provide energy and matter for a series of consumers, such as animals, that feed on producers. Organisms use food as a source of energy by breaking chemical bonds to release energy stored in the molecules or as building blocks for making new molecules needed by the organism. In other words, the molecules consumed can be used as both a source of energy and a source of matter. In these energy conversions between and within organisms, some energy is converted to heat, which is then lost from the ecosystem. Thus, energy flows through an ecosystem, entering as light energy and exiting as heat

✓ **CHECKPOINT**

What is the term for the genetic information that encodes for a protein?

■ Answer: gene

▶ Figure 1.17
Transformations of energy and matter in an ecosystem. Nutrients are recycled within an ecosystem, whereas energy flows into and out of an ecosystem.



energy. This flow of energy is represented by wavy lines in **Figure 1.17**.

Every object in the universe, both living and nonliving, is composed of matter. In contrast to energy flowing through an ecosystem, matter is recycled within an ecosystem. This recycling is represented by the blue circle in Figure 1.17. For example, minerals that plants absorb from the soil can eventually be recycled back into the soil when plants are decomposed by microorganisms. Decomposers, such as fungi and many bacteria, break down waste products and the remains of dead organisms, changing complex molecules into simple nutrients. The action of decomposers makes nutrients available to be taken up from the soil by plants again, thereby completing the cycle.

Within all living cells, a vast network of interconnected chemical reactions (collectively referred to as metabolism) continually converts energy from one form to another as matter is recycled. For example, as food molecules are broken down into simpler molecules, energy stored in the chemical bonds is released. This energy can be captured and used by the body (to power muscle contractions, for example). The atoms that made up the food can then be recycled (to build new muscle tissue, for example). Within all living organisms, there is a never-ending "chemical square dance" in which molecules swap chemical partners as they receive, convert, and release matter and energy. Within the ocean, for example, sunlight filtering through shallow water enables seagrass to grow. When a sea turtle grazes on seagrass, it obtains energy that it uses to swim and uses the molecules of matter as building blocks for cells within its own body.

Energy transformations can be disrupted, often with dire consequences. Consider what happens if you consume cyanide, one of the deadliest known poisons. Ingesting just 200 milligrams (about half the size of an aspirin tablet) causes death in humans. Cyanide is so toxic because it blocks an essential step within the metabolic pathway that harvests energy from glucose. When even a single protein within this pathway becomes inhibited, cells lose the ability to extract the energy stored in the chemical bonds of glucose. The rapid death that follows is a gruesome illustration of the importance of energy and matter transformations to life. Throughout your study of biology, you will see more examples of how living organisms regulate the transformation of energy and matter, from microscopic cellular processes such as photosynthesis (Chapter 7) and cellular respiration (Chapter 8), to ecosystem-wide cycles of carbon and other nutrients (Chapter 20), to global cycles of water across the planet (Chapter 18). ✓

✓ CHECKPOINT

1. What is the key difference between how energy and matter move in ecosystems?
2. What is the primary way by which energy leaves your body?

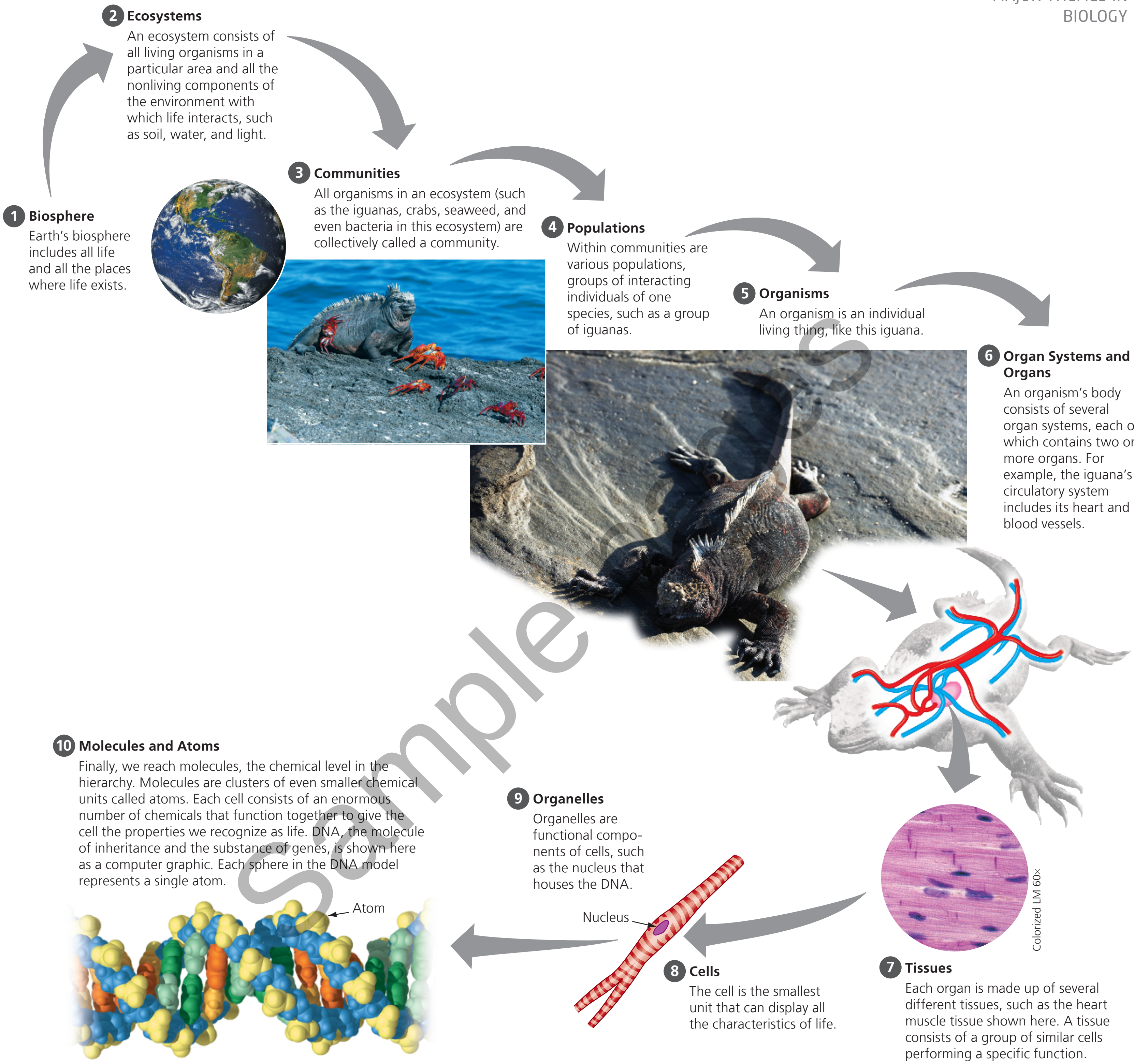
■ Answers: **1.** Energy moves through an ecosystem (entering and exiting), whereas matter is recycled within an ecosystem. **2.** as heat

Interactions within Biological Systems

The study of life extends from the microscopic level of the molecules and cells that make up organisms to the global level of the entire living planet. We can divide this enormous range into different levels of biological organization, each of which can be viewed from a system perspective. There are many interactions within and between these levels of biological systems.

Imagine zooming in from space to take a closer and closer look at life on Earth. **Figure 1.18** takes you on a tour that spans the levels of biological organization. The top of the figure shows the global level of the entire **biosphere**, which consists of all the environments on Earth that support life—including soil; oceans, lakes, and other bodies of water; and the lower atmosphere. At the other extreme of biological size and complexity are microscopic molecules such as DNA, the chemical responsible for inheritance. Zooming outward from the bottom to the top in the figure, you can see that it takes many molecules to build a cell, many cells to make a tissue, multiple tissues to make an organ, and so on. At each new level, novel properties emerge that are absent from the preceding one. These emergent properties are due to the specific arrangement and interactions of many parts into

▼ **Figure 1.18** **Zooming in on life.**



an increasingly complex system. Such properties are called emergent because they emerge as complexity increases. For example, life emerges at the level of the cell; a test tube full of molecules is not alive. The saying "the whole is greater than the sum of its parts" captures this idea. Emergent properties are not unique to life. A box of camera parts won't do anything, but if the parts are arranged and interact in a certain way, you can capture photographs. Add structures from a phone, and your camera and phone can interact to gain the ability to send photos to friends. New properties emerge as the complexity increases. Compared with such nonliving examples, however, the unrivaled complexity of biological systems makes the emergent properties of life especially fascinating to study.

Consider another example of interactions within biological systems, one that operates on a much larger level: global climate. For example, as the temperature of Earth's atmosphere rises, the oceans are becoming warmer. When the water is too warm, coral animals expel algae that live within them. As a result, the corals lose their color, a phenomenon called coral bleaching. The bleached coral fails to support other life that grows on and around the coral reef, thereby reducing the food supply available to sea turtles. The gases emitted from a coal plant in the Midwest of the United States can therefore affect a turtle swimming off the coast of Australia. Indeed, nearly two-thirds of the Great Barrier Reef of Australia experienced significant bleaching in 2016 and 2017, a development of great concern to marine biologists. Throughout our study of life, we will see countless interactions that operate within and between every level of the biological hierarchy shown in Figure 1.18. ✓

✓ **CHECKPOINT**

What is the smallest level of biological organization that can display all the characteristics of life?

■ Answer: a cell

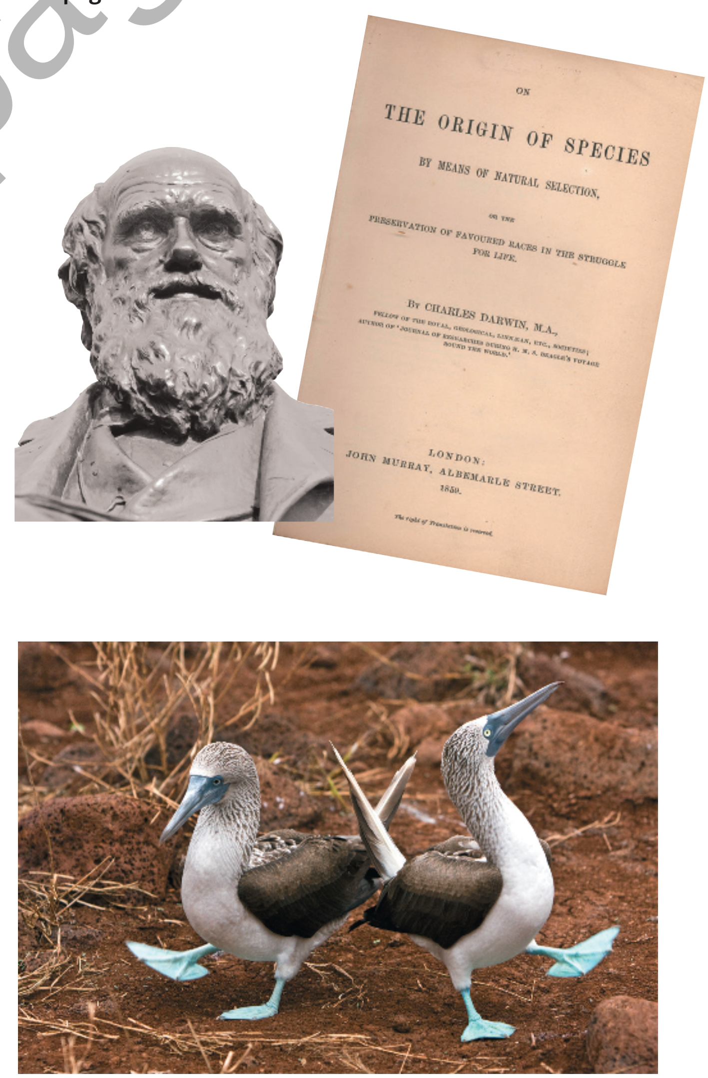
Evolution

Life is distinguished by both its unity and its diversity. Multiple lines of evidence point to life's unity, from the similarities seen among and between fossil and living organisms, to common cellular processes, to the universal chemical structure of DNA, the molecule of inheritance. The amazing diversity of life is on display all around you and is documented in zoos, nature shows, and natural history museums. It is remarkable how life can be both so similar (unity) and at the same time so different (diversity). The scientific explanation for this unity and diversity is **evolution**, the process of change that has transformed life on Earth from its earliest forms to the vast array of organisms living today. Evolution is the fundamental principle of life and the core theme that unifies all of biology. The theory of evolution by natural selection is the one principle that makes sense of everything we know about living organisms. Evolution can help us investigate and understand every aspect of life, from the tiny organisms that occupy the most remote habitats, to the diversity of species in our local environment, to the stability of the global environment. Therefore, every biology student should strive to understand evolution.

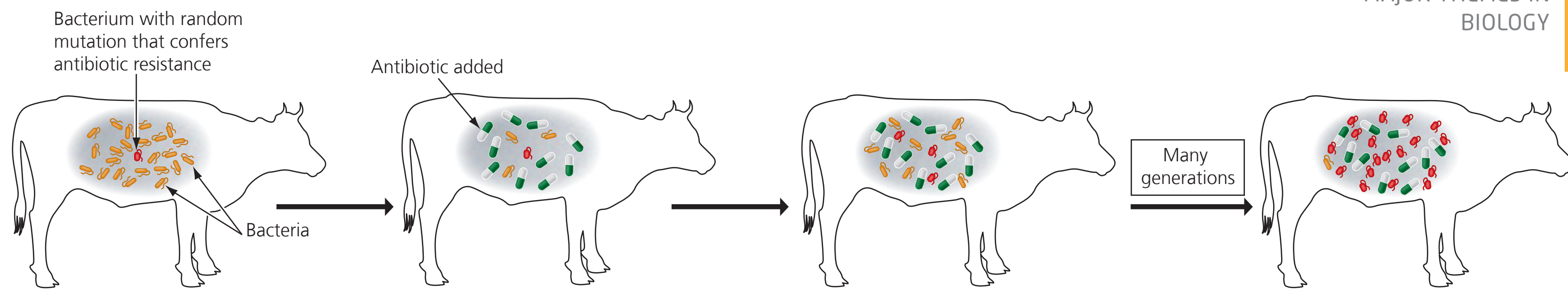
The evolutionary view of life came into focus in 1859 when Charles Darwin published one of the most influential books ever written: *On the Origin of Species by Means of Natural Selection* **(Figure 1.19)**. The first of two main points that Darwin presented in *The Origin of Species* was that species living today arose from a succession of ancestors that were different from them. Darwin called this process "descent with modification." This insightful phrase captures both the unity of life (descent from a common ancestor) and the diversity of life (modifications that evolved as species diverged from their ancestors).

Although other scholars had proposed similar ideas of descent with modification, Darwin was the first to propose a valid mechanism that explained how and why it occurs. This is the second main point of Darwin's book: The process of natural selection is the driving force of evolution. In the struggle for existence, those individuals with traits best suited to the local environment are more likely to survive and leave the greatest number of healthy offspring. It is this unequal reproductive success that Darwin called **natural selection** because the environment "selects" only certain heritable traits from those already existing. Natural selection does not promote or somehow encourage changes. Rather, mutations occur randomly. Natural selection "edits" those changes that have already occurred. If those traits can be inherited, they will be more common in the next generation. The results of natural selection are evolutionary adaptations, inherited traits that enhance survival in an organism's specific environment.

▼ Figure 1.19 Charles Darwin (1809–1882), *The Origin of Species*, and blue-footed boobies he observed on the Galápagos Islands.



▼ Figure 1.20 Natural selection in action.



1 **Population with varied inherited traits.** The bacteria vary in ability to resist the antibiotic. By chance, a few bacteria are resistant.

2 **Elimination of individuals with certain traits.** The majority of bacteria are killed by the antibiotic. The few resistant bacteria will tend to survive.

3 **Reproduction of survivors.** As the resistant bacteria reproduce, genes for antibiotic resistance are passed along to the next generation in greater frequency.

4 **Increasing frequency of traits that enhance survival and reproductive success.** Generation after generation, the bacteria population adapts to the environment by natural selection.

The world is rich with examples of natural selection. Consider the development of antibiotic-resistant bacteria **(Figure 1.20)**. Dairy and cattle farmers often add antibiotics to feed because doing so results in larger, more profitable animals. 1 The members of the bacteria population already, due to random mutation, vary in their susceptibility to an antibiotic. 2 Once the environment has been changed with the addition of antibiotics, some bacteria will succumb quickly and die, whereas others will survive. 3 Those that do survive will have the potential to multiply, producing offspring that will likely inherit the traits that enhance survival. 4 Over many generations, bacteria that are resistant to antibiotics will thrive in greater and greater numbers. Thus, feeding antibiotics to cows may promote the evolution of antibiotic-resistant bacterial populations.

As you'll see in Chapter 13, the theory of evolution by natural selection is supported by multiple lines of evidence—the fossil record, experiments, observations of natural selection in action, and genetic data. Evolution is the central theme that makes sense of everything we know and learn about biology. Throughout this text, we'll see many more examples of both the process and products of evolution.

To review the five unifying themes of biology, let's return to the green sea turtle **(Figure 1.21)**. Every topic in biology can be related to these big ideas. To emphasize evolution as the central theme of biology, we end each chapter with an Evolution Connection section. Let's end the chapter the way it began, by imagining yourself floating in the ocean. ✓

✓ CHECKPOINT

1. What is the modern term for what Darwin called "descent with modification"?
2. What mechanism did Darwin propose for evolution? What three-word phrase summarizes this mechanism?

■ Answers: **1.** evolution **2.** natural selection; unequal reproductive success

▼ Figure 1.21 Applying the major themes of biology to the study of the green sea turtle.

The relationship of structure to function. Flippers are adapted to cruising through the sea.

Information flow. DNA comparisons with other types of turtles reveal how genes account for the unique traits of this species.

Pathways that transform energy and matter. A diet of mainly low-nutrient foods results in slow growth.

Evolution. Fossils indicate the shell evolved from expanding backbones and ribs. Natural selection favored better protection, leading to the shell we see today.

Interactions within biological systems. Changing global climate patterns affect migration routes and the growth of the turtles' prey.

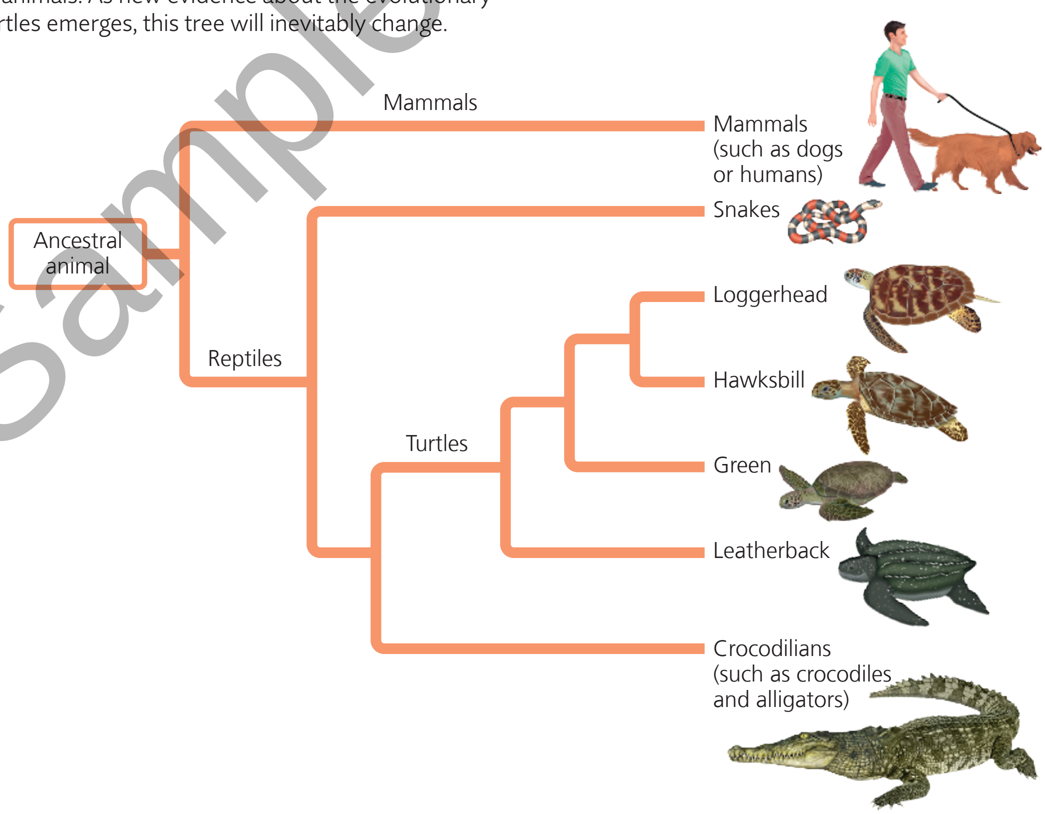
EVOLUTION CONNECTION **Swimming with the Turtles**

Turtles in the Tree of Life

Just as you have a family history, each species on Earth today represents one twig on a branching tree of life that extends back in time through ancestral species more and more remote. Analyzing DNA can determine relationships in a human family (settling questions of paternity, for example). Similarly, comparing DNA sequences from different species provides evidence of evolutionary relationships. The underlying assumption is that the more closely the DNA sequences of two species match, the more closely they are related. Such evidence can be used to generate an evolutionary tree, such as the one shown in **Figure 1.22**. Notice that this figure is highly abbreviated, showing just a few examples. Diagrams of evolutionary relationships generally take the form of branching trees, usually turned sideways and read from left (most ancient time) to right (most recent time).

Species that are very similar, such as the loggerhead and hawksbill turtles, share a common ancestor at a relatively recent branch point on the tree of life. In addition, all turtles can be traced back much further in time to an ancestor common to turtles, crocodiles, snakes, and all other reptiles. All reptiles have hard-shelled eggs, and such similarities are what we would expect if all reptiles descended from a common ancestor, a first reptile. And reptiles, mammals, and all other animals share a common ancestor—the first animal—even more ancient. Going further back still, at the cellular level, all life displays striking similarities. For example, all living cells are surrounded by an outer membrane of similar makeup and use structures called ribosomes to produce proteins. Such evolutionary analyses based on the structure of DNA provide insight into life both current and ancient. In this spirit, we will begin our investigation of biology by studying the chemistry of life (Chapter 2).

▼ **Figure 1.22 A partial family tree of animals.** This tree represents a hypothesis (a tentative model) based on both the fossil record and a comparison of DNA sequences in present-day animals. As new evidence about the evolutionary history of turtles emerges, this tree will inevitably change.



Chapter Review

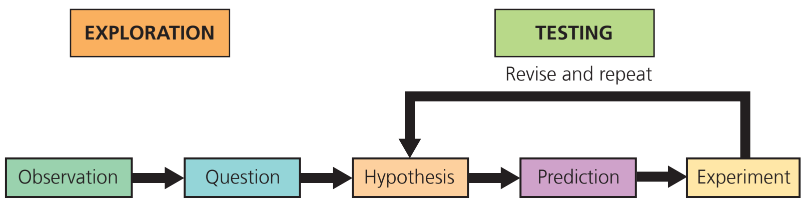
SUMMARY OF KEY CONCEPTS

The Scientific Study of Life

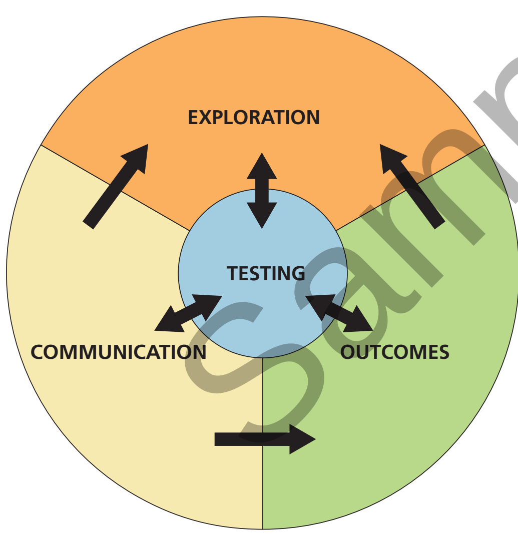
Biology is the scientific study of life.

An Overview of the Process of Science

It is important to distinguish scientific investigations from other ways of thinking because only scientific means of studying life qualify as biology. Science usually begins with exploration, either through observations recorded as data or by gathering information from reliable sources. Exploration often raises questions that can be tested by forming a hypothesis (a proposed explanation for your observations). Hypotheses can be investigated by further observations or by conducting experiments. This process sometimes takes the form of a series of steps that can lead to discovery:



Scientists often communicate their results through peer-reviewed publications. There is no fixed process of science. Each study proceeds through exploration, testing, communication, and outcomes in different ways.



Hypotheses, Theories, and Facts

A theory is a broad and comprehensive statement about the world that is supported by the accumulation of a great deal of verifiable evidence. A fact is a piece of information that can be verified by any independent observer.

Controlled Experiments

A controlled experiment involves running the same tests on two or more groups that differ in one variable. The control group does not receive the change under investigation, while the experimental group does. A blind experiment is one where information about the experiments is withheld from the participants and/or the experimenters.

Evaluating Scientific Claims

Be wary of pseudoscience that is falsely presented as following a process of science when it does not. You can learn to recognize reliable resources by looking for indicators.

The Properties of Life

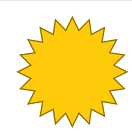
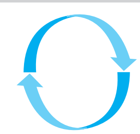
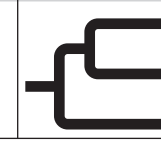
All life displays a common set of characteristics:

- order
- regulation
- growth and development
- energy processing
- response to the environment
- reproduction
- evolution
- cells

Major Themes in Biology

Throughout your study of biology, you will frequently come upon examples of five unifying themes:

MAJOR THEMES IN BIOLOGY

Structure/ Function	Information Flow	Energy Transformations	Interconnections within Systems	Evolution
				

The Relationship of Structure to Function At all levels of biology, structure and function are related. Changing structure often results in an altered function, and learning about a component's function will often give insight into its structure.

Information Flow Throughout living systems, information is stored, transmitted, and used. Within your body, genes provide instructions for building proteins, which perform many of life's tasks.

Pathways That Transform Energy and Matter Within ecosystems, nutrients are recycled, but energy flows through.

Interactions within Biological Systems Life can be studied on many levels, from molecules to the entire biosphere. As complexity increases, novel properties emerge. For example, the cell is the smallest unit that can possibly display all of the characteristics of life.

Evolution Charles Darwin established the ideas of evolution ("descent with modification") through natural selection (unequal reproductive success) in his 1859 publication *The Origin of Species*. Natural selection leads to adaptations to the environment, which—when passed from generation to generation—is the mechanism of evolution.

Mastering Biology

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SELF-QUIZ

1. Which is *not* a characteristic of all living organisms?
   a. growth and development
   b. composed of multiple cells
   c. complex yet organized
   d. uses energy
2. Place the following levels of biological organization in order from smallest to largest: atom, biosphere, cell, ecosystem, molecule, organ, organism, population, tissue. Which is the smallest level capable of demonstrating all of the characteristics of life?
3. Plants use the process of photosynthesis to convert the energy in sunlight to chemical energy in the form of sugar. While doing so, they consume carbon dioxide and water and release oxygen. Explain how this process functions in both the cycling of chemical nutrients and the flow of energy through an ecosystem.
4. How does natural selection cause a population to become adapted to its environment over time?
5. Which of the following are the proper components of the scientific method?
   a. experiment, conclusion, application.
   b. question, observation, experiment, analysis, prediction.
   c. observation, question, hypothesis, prediction, experiment, conclusion.
   d. observation, question, opinion, conclusion, hypothesis.
6. Which statement best distinguishes hypotheses from theories in science?
   a. Theories are hypotheses that have been proven.
   b. Hypotheses are tentative guesses; theories are correct answers to questions about nature.
   c. Hypotheses usually are narrow in scope; theories have broad explanatory power and are supported by a lot of evidence.
   d. Hypotheses and theories mean essentially the same thing in science.
7. ______ is the core theme that unifies all areas of biology.
8. What distinguishes a fact from an opinion?
9. Match each of the following terms to the phrase that best describes it.
   a. Natural selection — 1. A testable idea
   b. Evolution — 2. Descent with modification
   c. Hypothesis — 3. Unequal reproductive success
   d. Biosphere — 4. All life-supporting environments on Earth

For answers to the Self Quiz, see Appendix D.

IDENTIFYING MAJOR THEMES

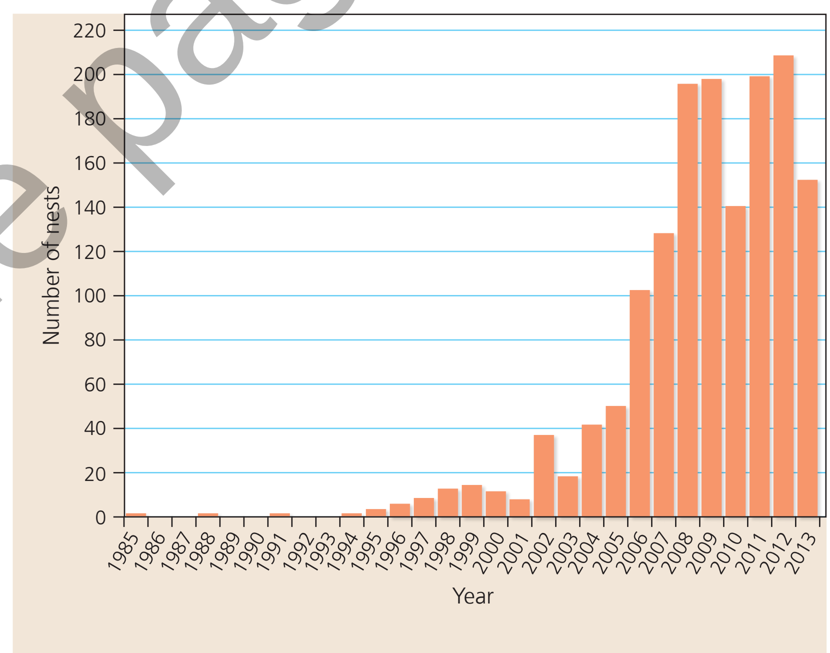
For each statement, identify which major theme is evident (the relationship of structure to function, information flow, pathways that transform energy and matter, interactions within biological systems, or evolution) and explain how the statement relates to the theme. If necessary, review the theme descriptions in this chapter.

10. By comparing genes between green sea turtles and humans, insight can be gained into how those genes encode specific physical traits.
11. Although green sea turtles consume a lot of vegetation, they get few nutrients from each mouthful, requiring them to graze frequently.
12. As global climate changes, green sea turtles alter many aspects of their behavior.

For answers to Identifying Major Themes, see Appendix D.

THE PROCESS OF SCIENCE

13. Figure 1.20 depicts the selection of a trait—the resistance to an antibiotic—in a population of bacteria. Let us assume that this resistance is conferred by a gene that helps to neutralize or inactivate the antibiotic and is only carried by the resistant bacteria. What would happen to the bacterial population if this antibiotic is banned? Develop a hypothesis that is consistent with Darwin's theory of natural selection.
14. **Interpreting Data** The Kemp's ridley sea turtle (*Lepidochelys kempii*) is a critically endangered species. The graph presents the number of Kemp's ridley sea turtle nests found in the Padre Island National Seashore in Texas over a span of years. Write a one-sentence summary of the results presented in the graph.



BIOLOGY AND SOCIETY

15. The development of both drugs and household items typically involves biomedical and/or biochemical research. Select three drugs and three household items, and devise hypothetical flowcharts, like the one depicted in Figure 1.2, which delineate the process of development of each of these.
16. Check the presence of the word "biological" (or "bio") on the containers of food and cleaning products. How does its use on commercial products relate to the scientific definition of biology?