Sixteenth Edition

INQUIRY INTO LIFE

Sylvia S. Mader
Michael Windelspecht

McGraw Hill Education

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ABOUT THE AUTHORS

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Sylvia S. Mader

Sylvia Mader has authored several nationally recognized biology texts published by McGraw-Hill. Educated at Bryn Mawr College, Harvard University, Tufts University, and Nova Southeastern University, she holds degrees in both biology and education. Over the years she has taught at University of Massachusetts, Lowell; Massachusetts Bay Community College; Suffolk University; and Nathan Mayhew Seminars. Her ability to reach out to science-shy students led to the writing of her first text, *Inquiry into Life*. Highly acclaimed for her crisp and entertaining writing style, her books have become models for others who write in the field of biology.

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Michael Windelspecht

As an educator, Dr. Windelspecht has taught introductory biology, genetics, and human genetics in the online, traditional, and hybrid environments at community colleges, comprehensive universities, and military institutions. For over a decade he served as the Introductory Biology Coordinator at Appalachian State University, where he directed a program that enrolled over 4,500 students annually.

He received degrees from Michigan State University (BS, zoology-genetics) and the University of South Florida (PhD, evolutionary genetics) and has published papers in areas as diverse as science education, water quality, and the evolution of insecticide resistance. His current interests are in the analysis of data from digital learning platforms for the development of personalized microlearning assets and next-generation publication platforms. He is currently a member of the National Association of Science Writers and several science education associations. He has served as the keynote speaker on the development of multimedia resources for online and hybrid science classrooms. In 2015, he won the DevLearn HyperDrive competition for a strategy to integrate student data into the textbook revision process.

As an author and editor, Dr. Windelspecht has over 20 reference textbooks and multiple print and online lab manuals. He has founded several science communication companies, including Ricochet Creative Productions, which actively develops and assesses new technologies for the science classroom. You can learn more about Dr. Windelspecht by visiting his website at www.michaelwindelspecht.com.

Contributor

Dave Cox serves as Professor of Biology at Lincoln Land Community College, in Springfield, Illinois. He was educated at Illinois College and Western Illinois University. As an educator, Professor Cox teaches introductory biology for nonmajors in the traditional classroom format as well as in a hybrid format. He also teaches biology for majors, and marine biology and biological field studies as study-abroad courses in Belize. He is the co-owner of Howler Publications, a company that specializes in scientific study abroad courses. Professor Cox served as a contributor to both *Inquiry 14e* and *Human Biology 13e*. He also develops educational resources for the ecotourism industry in Belize.

PREFACE

Goals of *Inquiry into Life* 16e

Dr. Sylvia Mader's text, *Inquiry into Life,* was originally developed to reach out to science-shy students. The text now represents one of the cornerstones of introductory biology education. *Inquiry into Life* was founded on the belief that teaching science from a human perspective, coupled with human applications, would make the material more relevant to the student. Interestingly, even though it has been over 40 years since the first edition was published, this style of relevancy-based education remains the focus of the national efforts to increase scientific literacy in the general public.

Our modern society is based largely on advances in science and technology over the past few decades. As we present in this text, there are many challenges facing humans, and an understanding of how science can help analyze, and offer solutions to these problems is critical to our species' health and survival.

The front cover of this text was chosen to indicate not only that humans are the stewards of the planet, but that we also possess the ability to influence, both positively and negatively, all of the inhabitants of our world. Therefore, it is important that we know not only why we are different, but how we are the same as the species we share the planet with. Students in today's world are being exposed, almost on a daily basis, to exciting new discoveries and insights that, in many cases, were beyond our predictions even a few short years ago. It is our task, as instructors, not only to make these findings available to our students, but to enlighten students as to why these discoveries are important to their lives and society. At the same time, we must provide students with a firm foundation in those core principles on which biology is founded, and in doing so, provide them with the background to keep up with the many discoveries still to come.

This text, along with the *Inquiry into Life* 15.1 edition, represents an ongoing project in the development of a continuously updated textbook. As scientists and educators, the authors of this text are well aware that scientific discovery is a dynamic process. Fortunately, the advances in digital publishing are allowing authors to update content on an ongoing basis, which in turn is promoting the ability to update content on a regular basis. This text represents the prototype of those efforts. Specifically, the authors sought to:

1. Update chapter openers and readings within the text to reflect more recent discoveries or topics of interest in the life sciences.
2. Update statistics, maps, and tables to reflect changes in our scientific understanding of the topic.
3. Assess and redesign art to better fit the digital learning environment.
4. Develop a relevancy module to supplement the content of the text. These relevancy modules allow the instructor to engage students with topics that are not normally covered in an introductory textbook.

Relevancy

The use of real-world examples to demonstrate the importance of biology in the lives of students is widely recognized as an effective teaching strategy for the introductory biology classroom. Students want to learn about the topics they are interested in. The development of relevancy-based resources is a major focus for the authors of the Mader series of texts. Some examples of how we have increased the relevancy content of this edition include:

Relevancy Modules

Relevancy modules have been authored to accompany each unit in Mader/Windelspecht *Inquiry into Life*. These modules demonstrate the connections between biological content and topics that are of interest to society as a whole. Each module consists of an introductory video, an overview of basic scientific concepts, and then a closer look at the application of these concepts to the topic. Discussion and assessment questions, specific to the modules, are also available.

These modules are available as a supplementary eBook to the existing text within Connect, and may be assigned by the instructor for use in a variety of ways in the classroom. Examples of topics covered include cancer biology, fermentation science, weed evolution, antibiotic resistance, mega crops, biology of weight gain, and climate change. New topics are planned for launch each year to keep these resources current.

BioNow Videos

The BioNow series of videos, narrated and produced by educator Jason Carlson, provide a relevant, applied approach that allows your students to feel they can actually do and learn biology themselves. While tying directly to the content of your course, the videos help students relate their daily lives to the biology you teach and then connect what they learn back to their lives.

Each video provides an engaging and entertaining story about applying the science of biology to a real situation or problem. Attention is given to using tools and techniques that the average person would have access to, so your students see the science as something they could do and understand.

RicochetScience Website

The RicochetScience.com website, managed by Dr. Michael Windelspecht, provides content that is of interest to students who are not majoring in the sciences. For example, the PopScience articles on this site provide an excellent focus for classroom discussions on topics that are currently being debated in society, such as vaccines. The content is organized by the same topic areas that are the focus of the relevancy modules, making it simple for instructors to find and utilize these resources. The site also features videos and tutorial animations to assist the students in recognizing the relevancy of what they are learning in the classroom.

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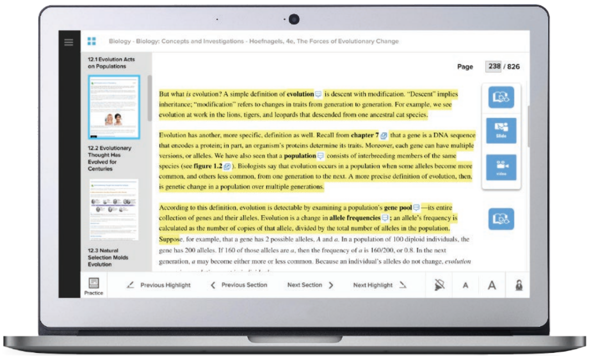

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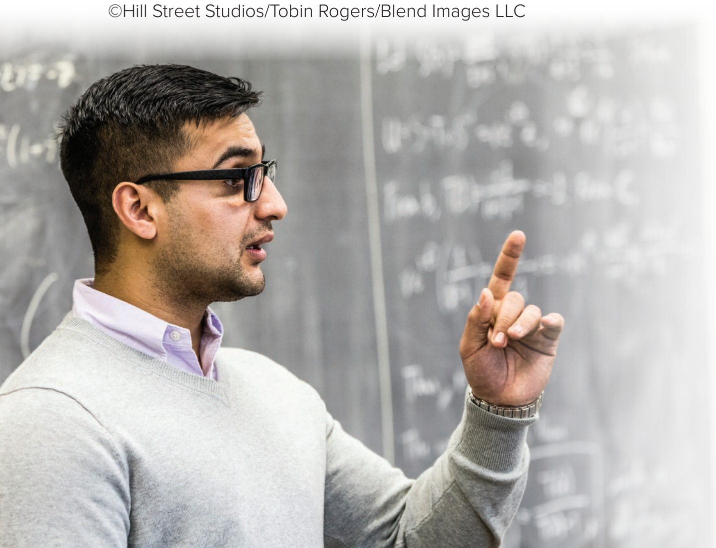

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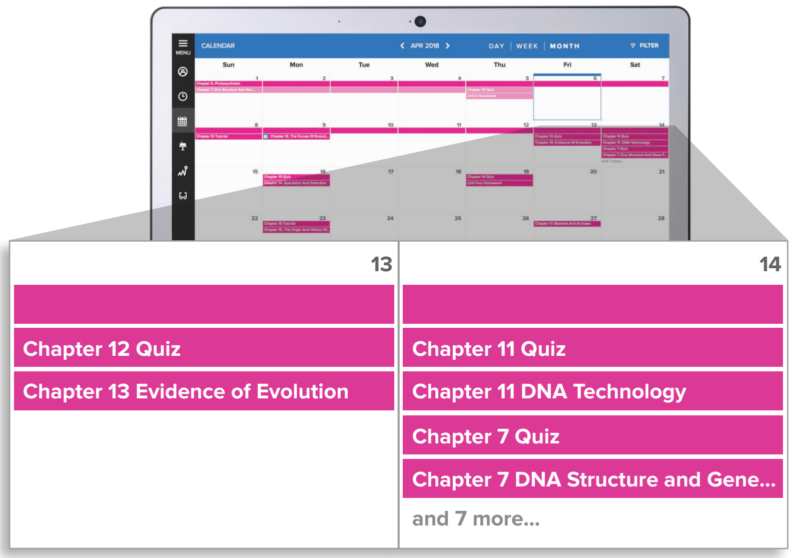

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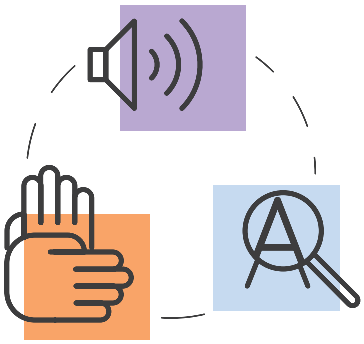

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ACKNOWLEDGMENTS

Dr. Sylvia Mader is one of the icons of science education. Her dedication to her students, coupled with her clear, concise writing style, has benefited the education of thousands of students over the past four decades. As an educator, it is an honor to continue her legacy and to bring her message to the next generation of students.

As always, I had the privilege to work with a phenomenal group of people on this edition. I would especially like to thank you, the numerous instructors who have shared e-mails with me or have invited me into your classrooms, both physically and virtually, to discuss your needs as instructors and the needs of your students. You are all dedicated and talented teachers, and your energy and devotion to quality teaching is what drives a textbook revision.

Many dedicated and talented individuals assisted in the development of this edition of *Inquiry into Life*. I am very grateful for the help of so many professionals at McGraw-Hill who were involved in bringing this book to fruition. Therefore, I would like to thank the following:

- The product developer, Anne Winch, for her patience and impeccable ability to keep me focused.
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- Lori Hancock and Jo Johnson, for the photos within this text. Biology is a visual science, and your contributions are evident on every page.
- Dawnelle Krouse, Michael McGee, and Sharon O'Donnell, who acted as my proofreaders and copyeditors for this edition.
- Jane Peden, for her behind-the-scenes work that keeps us all functioning.

As both an educator and an author, communicating the importance of science represents one of my greatest passions. Our modern society is based largely on advances in science and technology over the past few decades. As I present in this text, there are many challenges facing humans, and an understanding of how science can help analyze, and offer solutions to, these problems is critical to our species' health and survival.

I also want to acknowledge my family and friends for all of their support. My wife, Sandy, who has never wavered in her energy and support of my projects. Over the course of my work with McGraw-Hill, I have watched the natural curiosity of my children, Devin and Kayla, develop. Thank you both for your motivation in making our world a better place.

Michael Windelspecht, PhD
Blowing Rock, NC

Reviewers for This Edition

I would like to thank the individuals below for taking the time to review the content of the previous edition. Your comments and suggestions played an important part of this revision.

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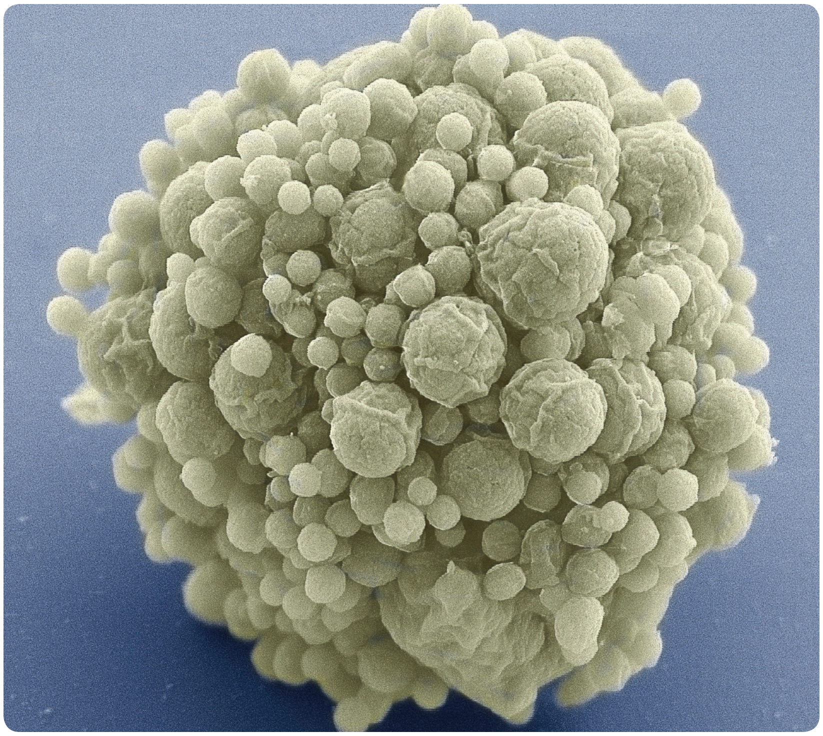
SCIENCE IN YOUR LIFE ▶ HEALTH

SCIENCE IN YOUR LIFE ▶ ECOLOGY

SCIENCE IN YOUR LIFE ▶ SCIENTIFIC INQUIRY



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CHAPTER 1

Biology: The Study of Life

Artificial Life

What are the minimal requirements for life? That question has occupied the minds of philosophers and scientists for thousands of years. However, in just the past decade, answers to this question have begun to emerge from a developing field of scientific study called artificial life.

One of the first of these studies occurred in 2010, when a research team led by Craig Venter (a pioneer in genetic research) was successful in removing the genetic information contained within the DNA of a bacterium and replacing it with a synthetic form of DNA.

In 2016, the same group of researchers took their research one step further. This time, they asked what minimal instructions were needed by a cell for it to be considered alive. They constructed a cell that functioned on just 473 genes (humans have around 19,000). In the process, they not only narrowed in on what the minimal requirements for life are, but also created the first example of an artificial species.

The development of artificial life opens up the opportunity for humans to construct cells that perform specific tasks, such as producing insulin, cleaning toxic waste, or producing fuel more efficiently. However, there are concerns about these new endeavors, and some scientists are urging constraint until the risks have been determined.

In this chapter, we are going to explore the concept of life by examining the general characteristics that are shared by all living organisms on our planet.

As you read through this chapter, think about the following questions:

1. What are the basic characteristics that define life?
2. How do the processes of adaptation and evolution shape life over time?
3. How might the use of artificial life help scientists address some of the challenges facing society?

CHAPTER OUTLINE

1.1 The Characteristics of Life

Learning Outcomes

Upon completion of this section, you should be able to

1. Identify the basic characteristics of life.
2. Distinguish between the levels of biological organization.
3. Recognize the importance of adaptation and evolution to life.

Life. Everywhere we look, from the deepest trenches of the oceans to the geysers of Yellowstone, we find that planet Earth is teeming with life. Without life, our planet would be nothing but a barren rock hurtling through space. The variety of life on Earth is staggering. Recent estimates suggest that there are around 8.7 million species on the planet, but this number does not include the bacteria (Fig. 1.1), which historically have been difficult to identify. The variety of living organisms ranges in size from bacteria, much too small to be seen by the naked eye, all the way up to 100-foot-tall giant sequoia trees or 40-ton humpback whales. Humans are just one of those species.

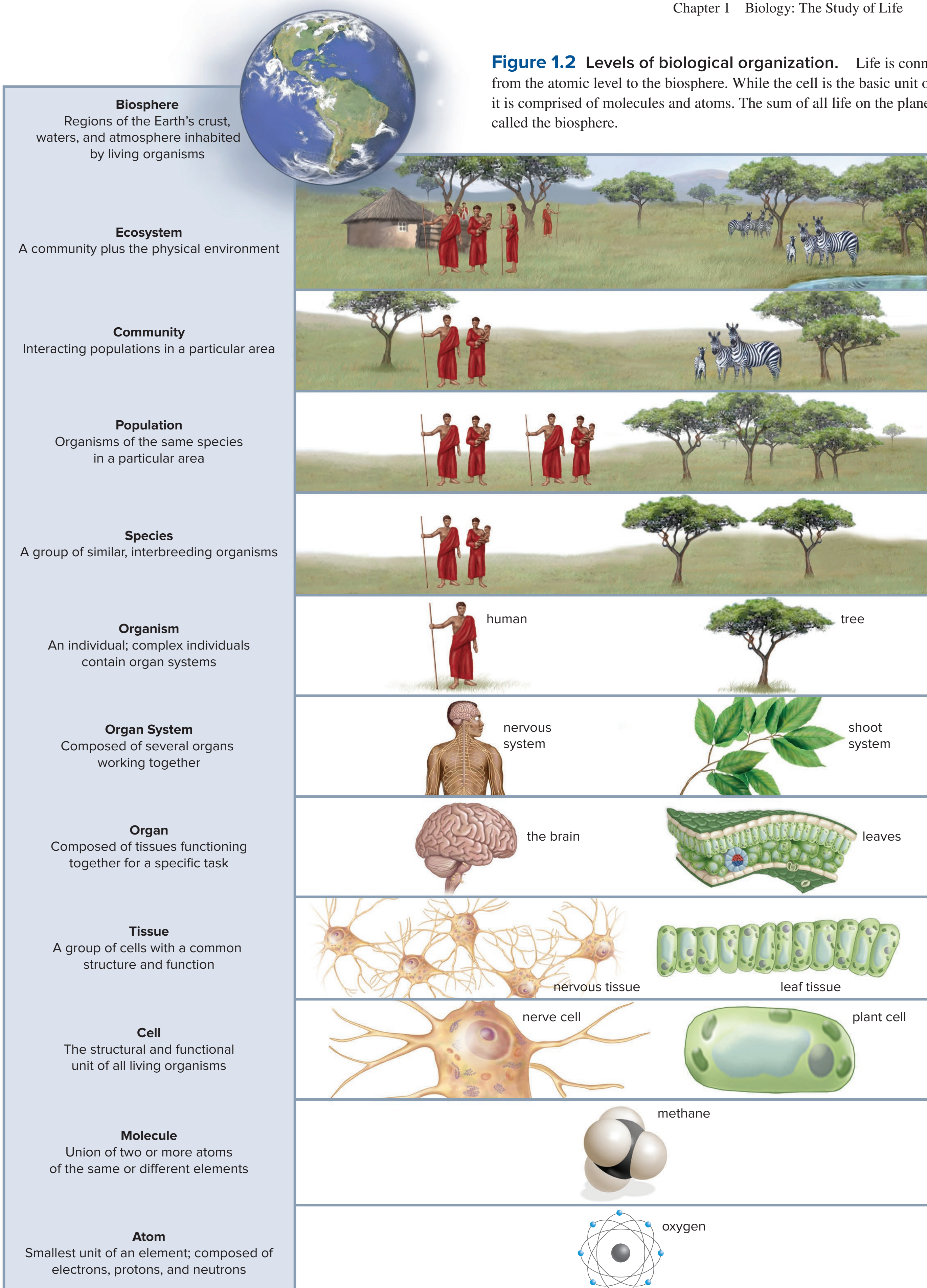
The diversity of life seems overwhelming, and yet all living organisms have certain characteristics in common. Taken together, these characteristics give us insight into the nature of life and help us distinguish living from nonliving organisms. All life generally shares the following characteristics: (1) is organized, (2) requires materials and energy, (3) has the ability to reproduce and develop, (4) responds to its environment, (5) maintains an internal environment, and (6) has the capacity to adapt to its environment. Next, we will explore each of these characteristics in more detail.

Life Is Organized

Life can be organized in a hierarchy of levels (Fig. 1.2). In trees, humans, and all other organisms, **atoms** join together to form

Figure 1.1 Diversity of life on Earth. If aliens ever visit our corner of the universe, they will be amazed at the diversity of life on our planet. Yet despite its diversity, all life shares some common characteristics. (whales): ©iStockphoto/Getty Images; (*E. coli*): Source: USDA-ARS/Eric Erbe & Chris Pooley, photographers; (sequoia): ©Robert Glusic/Getty Images; (Earth): ©Ingram Publishing/Alamy; (mushroom): ©IT Stock/age fotostock; (*Homo sapiens*): ©Blend Images/Ariel Skelley/Getty Images; (*Euglena*): ©blickwinkel/Alamy

Figure 1.2 Levels of biological organization. Life is connected from the atomic level to the biosphere. While the cell is the basic unit of life, it is comprised of molecules and atoms. The sum of all life on the planet is called the biosphere.



molecules, such as DNA molecules that occur within cells. A **cell** is the smallest unit of life, and some organisms are single-celled. In multicellular organisms, a cell is the smallest structural and functional unit. For example, a human nerve cell is responsible for conducting electrical impulses to other nerve cells. A **tissue** is a group of similar cells that perform a particular function. Nervous tissue is composed of millions of nerve cells that transmit signals to all parts of the body. Several tissues then join together to form an **organ.** The main organ that receives signals from nerves is the brain. Organs then work together to form an **organ system.** In the nervous system, the brain sends messages to the spinal cord, which in turn sends them to body parts through spinal nerves. In describing the levels of biological organization, the term **organism** is used to describe an individual that is a collection of multiple organ systems. However, the term is also used generally to indicate an individual member of a species.

The levels of biological organization extend beyond the individual. All the members of one **species** (a group of interbreeding organisms) in a particular area belong to a **population.** A tropical grassland may have a population of zebras, acacia trees, and humans, for example. The interacting populations of the grasslands make up a **community.** The community of populations interacts with the physical environment to form an **ecosystem.** Finally, all the Earth's ecosystems collectively make up the **biosphere.**

Life Requires Materials and Energy

Living organisms need an outside source of materials and energy to maintain their organization and carry on life's other activities. Plants, such as trees, use carbon dioxide, water, and solar energy to make their own food. Humans and other animals acquire materials and energy by eating food.

The food we eat provides nutrients, which cells use as building blocks or for **energy**—the capacity to do work. Cells use energy from nutrients to carry out everyday activities. Some nutrients are broken down completely by chemical reactions to provide the necessary energy to carry out other reactions, such as building proteins. The term **metabolism** is used to describe all of the chemical reactions that occur in a cell. Cells need energy to perform their metabolic functions, and it takes work to maintain the organization of a cell, as well as to maintain an organism.

The ultimate source of energy for nearly all life on Earth is the sun. Plants and certain other organisms are able to capture solar energy and carry on photosynthesis, a process that transforms solar energy into the chemical energy of organic nutrient molecules. All life on Earth acquires energy by metabolizing nutrient molecules made by photosynthesizers. This applies even to plants themselves.

The energy and chemical flow between organisms also defines how an ecosystem functions (Fig. 1.3). Within an ecosystem, chemical cycling and energy flow begin when producers, such as grasses, take in solar energy and inorganic nutrients to produce food (organic nutrients) by photosynthesis. Chemical cycling (aqua arrows in Fig. 1.3) occurs as chemicals move from one population to another in a food chain, until death and decomposition allow inorganic nutrients to be returned to the producers once again. Energy (red arrows in Fig. 1.3), on the other hand, flows from the sun through plants and the other members of the food chain as they feed on one another. The energy gradually dissipates and returns to the atmosphere as heat. Because energy does not cycle, ecosystems could not stay in existence without solar energy and the ability of photosynthetic organisms to absorb it.

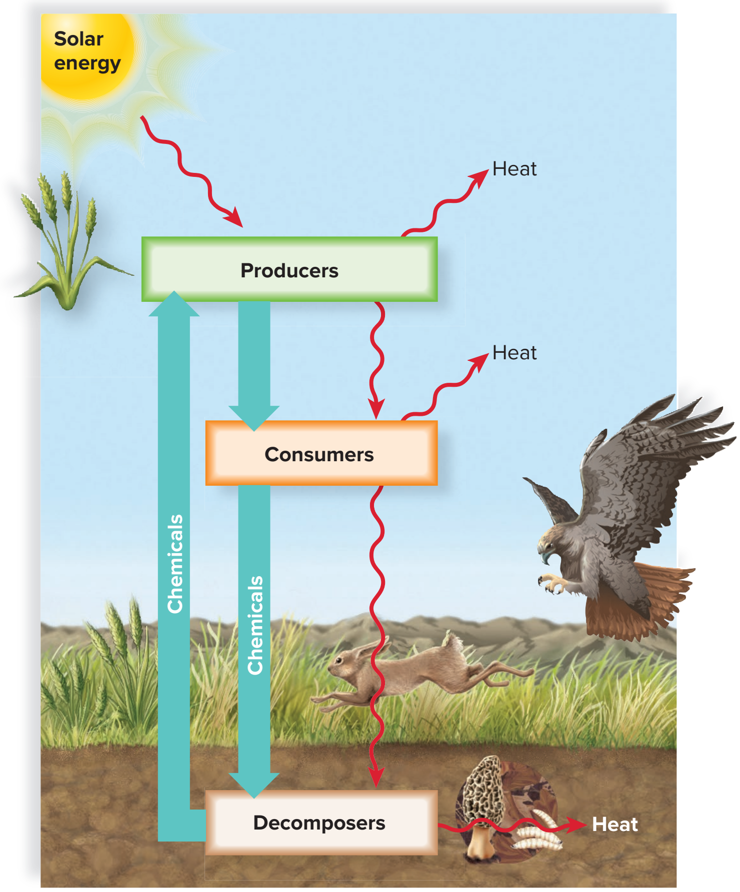


Figure 1.3 Chemical cycling and energy flow in an ecosystem. In an ecosystem, chemical cycling (aqua arrows) and energy flow (red arrows) begin when plants use solar energy and inorganic nutrients to produce their own food. Chemicals and energy are passed from one population to another in a food chain. Eventually, energy dissipates as heat. With the death and decomposition of organisms, chemicals are returned to living plants once more.

Energy flow and nutrient cycling in an ecosystem climate largely determine not only where different ecosystems are found in the biosphere, but also what communities are found in the ecosystem. For example, deserts exist in areas of minimal rain, while forests require much rain. The two most biologically diverse ecosystems—tropical rain forests and coral reefs—occur where solar energy is most abundant. One example of an ecosystem in North America is the grasslands, which are inhabited by populations of rabbits, hawks, and various types of grasses, among many others. These populations interact with each other by forming food chains in which one population feeds on another. For example, rabbits feed on grasses, while hawks feed on rabbits and other organisms.

Life Has the Capacity to Reproduce and Develop

Life comes only from life. All forms of life have the capability of **reproduction,** or to make another organism like themselves. Bacteria, protists, and other single-celled organisms simply split in

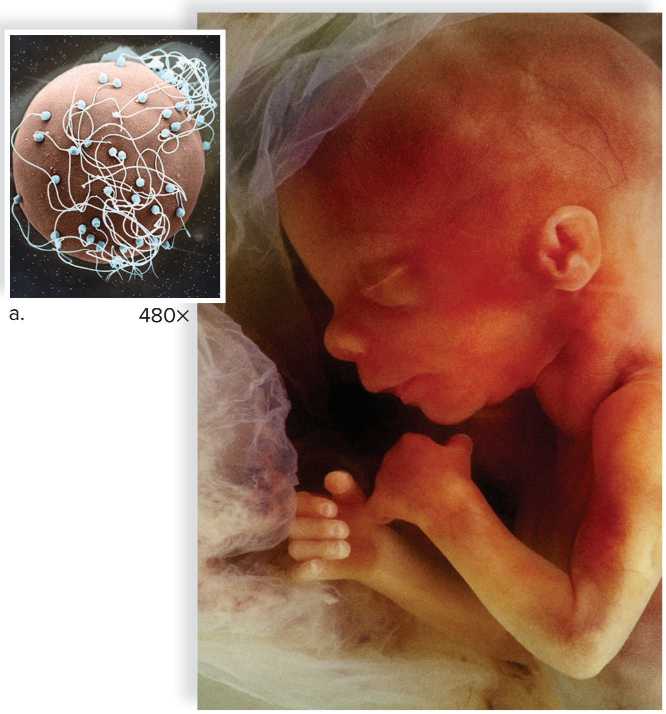


Figure 1.4 Growth and development define life. Following the (**a**) fertilization of an egg cell by a sperm cell (**b**) humans grow and develop. All life exhibits the characteristics of growth and development.
(a): ©David M. Phillips/Science Source; (b): ©Brand X Pictures/Punchstock

two. In most multicellular organisms, the reproductive process begins with the pairing of a sperm from one partner and an egg from the other partner. The union of sperm and egg (Fig 1.4), followed by many cell divisions, results in an immature stage, which proceeds through stages of **development,** or change, to become an adult.

When living organisms reproduce, their **genes,** or genetic instructions, are passed on to the next generation. Random combinations of sperm and egg, each of which contains a unique collection of genes, ensure that the offspring has new and different characteristics. An embryo develops into a whale, a yellow daffodil, or a human because of the specific set of genes it inherits from its parents. In living organisms, the genes are made of long **DNA (deoxyribonucleic acid)** molecules. DNA provides the blueprint, or instructions, for the organization and metabolism of the particular organism. All cells in a multicellular organism contain the same set of genes, but only certain genes are turned on in each type of specialized cell. You may notice that not all members of a species, including humans, are exactly the same, and that there are obvious differences between species. These differences are the result of **mutations,** or inheritable changes in the genetic information. Mutation provides an important source of variation in the genetic information. However, not all mutations are bad—the observable differences in eye and hair color are examples of mutations.

Life Responds to Its Environment

Right now, your eyes and ears are receiving stimuli from the external environment. If there is a loud noise nearby, your natural tendency is to look in that direction. All organisms respond to information, called stimuli, from their environment. This may be as simple as the movement toward food, or away from a predator. Movement in animals, including humans, is dependent upon their nervous and musculoskeletal systems. Other living organisms use a variety of mechanisms in order to move. The leaves of plants track the passage of the sun during the day, and when a houseplant is placed near a window, hormones help its stem bend to face the sun.

The movement of an organism, whether self-directed or in response to a stimulus, constitutes a large part of its **behavior.** Behavior is largely directed toward minimizing injury, acquiring food, and reproducing.

Life Maintains an Internal Environment

The internal environment of your body, and every cell in your body, is kept relatively stable. For example, human body temperature will show only a slight fluctuation throughout the day. Also, the body's ability to maintain a normal internal temperature is somewhat dependent on the external temperature—we will die if the external temperature becomes too hot or cold. This tendency toward a stable environment is called **homeostasis,** and it is the way that a living organism distinguishes itself from its environment.

Organisms have intricate feedback and control mechanisms that do not require any conscious activity. These mechanisms may be controlled by one or more tissues themselves or by the nervous system. When you are studying and forget to eat lunch, your liver releases stored sugar to keep blood sugar levels within normal limits. Many organisms depend on behavior to regulate their internal environment. In animals, these behaviors are controlled by the nervous system and are usually not consciously controlled. For example, a lizard may raise its internal temperature by basking in the sun, or cool down by moving into the shade.

Life Has the Ability to Adapt

Throughout the nearly 4 billion years that life has been on Earth, the environment has constantly been changing. For example, glaciers that once covered much of the world's surface 10,000–15,000 years ago have since receded, and many areas that were once covered by ice are now habitable. On a smaller scale, a hurricane or fire could drastically change the landscape in an area quite rapidly.

As the environment changes, some individuals of a species (a group of organisms that can successfully interbreed and produce fertile offspring) may possess certain features that make them better suited to the new environment. We call such features **adaptations.** For example, consider a hawk, which can catch and eat a rabbit. A hawk, like other birds, can fly because it has hollow bones, which is an adaptation. Similarly, its strong feet can take the shock of a landing after a hunting dive, and its sharp claws can grab and hold onto prey. As is presented in the Scientific Inquiry feature, "Adapting to Life at High Elevations," humans also exhibit adaptations to their environment.

Individuals of a species that are better adapted to their environment tend to live longer and produce more offspring than other individuals. This differential reproductive success, called **natural selection,** results in changes in the characteristics of a population (all the members of a species within a particular area) through

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Adapting to Life at High Elevations

Humans, like all other organisms, have an evolutionary history. This means not only that we share common ancestors with other animals, but also that over time we demonstrate adaptations to changing environmental conditions. One study of populations living in the high-elevation mountains of Tibet (Fig. 1A) demonstrates how the processes of evolution and adaptation influence humans.

Normally, if a person moves to a higher altitude, his or her body responds by making more hemoglobin, the component of blood that carries oxygen, which thickens the blood. For minor elevation changes, this does not present much of a problem. But for people who live at extreme elevations (some people in the Himalayas can live at elevations of over 13,000 ft, or close to 4,000 m), this can present a number of health problems, including chronic mountain sickness, a disease that affects people who live at high altitudes for extended periods of time. The problem is that, as the amount of hemoglobin increases, the blood thickens and becomes more viscous. This can cause elevated blood pressure, or hypertension, and an increase in the formation of blood clots, both of which have negative physiological effects.

Figure 1A Humans' adaptations to their environments. Humans have adaptations that allow them to live at high altitudes, such as these individuals in Tibet.

Because high hemoglobin levels would be a detriment to people at high elevations, it makes sense that natural selection would favor individuals who produced less hemoglobin at high elevations. Such is the case with the Tibetans in this study. Researchers have identified an allele of a gene that reduces hemoglobin production at high elevations. Comparisons between Tibetans at both high and low elevations strongly suggest that selection has played a role in the prevalence of the high-elevation allele.

The gene is *EPSA1,* located on chromosome 2 of humans. *EPSA1* produces a transcription factor, which basically regulates which genes are turned on and off in the body, a process called gene expression. The transcription factor produced by *EPSA1* has a number of functions in the body. For example, in addition to controlling the amount of hemoglobin in the blood, this transcription factor also regulates other genes that direct how the body uses oxygen.

When the researchers examined the variations in *EPSA1* in the Tibetan population, they discovered that their version greatly reduces the production of hemoglobin. Therefore, the Tibetan population has lower hemoglobin levels than people living at lower altitudes, allowing these individuals to escape the consequences of thick blood.

How long did it take for the original population to adapt to living at higher elevations? Initially, the comparison of variations in these genes between high-elevation and low-elevation Tibetan populations suggested that the event may have occurred over a 3,000-year period. But researchers were skeptical of those data because they represented a relatively rapid rate of evolutionary change. Additional studies of genetic databases yielded an interesting finding—the *EPSA1* gene in Tibetans was identical to a similar gene found in an ancient group of humans called the Denisovans (see Section 32.5). Scientists now believe that the *EPSA1* gene entered the Tibetan population around 40,000 years ago, either through interbreeding between early Tibetans and Denisovans, or from one of the immediate ancestors of this lost group of early humans.

Questions to Consider

1. What other environments do you think could be studied to look for examples of human adaptation?
2. In addition to hemoglobin levels, do you think that people at high elevations may exhibit other adaptations?

time. That is, adaptations that result in higher reproductive success tend to increase in frequency in a population from one generation to the next. This change in the frequency of traits in populations and species is called **evolution.**

Evolution explains both the unity and diversity of life. As stated at the beginning of this chapter, all organisms share the same basic characteristics of life because we all share a common ancestor—the first cell or cells—that arose nearly 4 billion years ago. During the past 4 billion years, the Earth's environment has changed drastically, and the diversity of life has been shaped by the evolutionary responses of organisms to these changes.

Check Your Progress 1.1

1. List the common characteristics of all living organisms.
2. Trace the organization of life from the cell to the biosphere.
3. Explain how adaptations relate to evolutionary change.

1.2 The Classification of Organisms

Learning Outcomes

Upon completion of this section, you should be able to

1. Describe how living organisms are classified.
2. Distinguish between the three domains of life.
3. Explain the role of supergroups in the classification of life.

Because life is so diverse, it is helpful to group organisms into categories. **Taxonomy** is the discipline of identifying and grouping organisms according to certain rules. Taxonomy makes sense out of the bewildering variety of life on Earth and is meant to provide valuable insight into evolution. **Systematics** is the study of the evolutionary relationships between species. As systematists learn more about living organisms, the taxonomy often changes. DNA technology is now widely used by systematists to revise current information and to discover previously unknown relationships between organisms.

Several of the basic classification categories, also called *taxa,* are **domain, kingdom, phylum, class, order, family, genus,** and, finally, **species.** These are listed in order from the most inclusive (domains) to the least inclusive (species).

Domains

Domains are the largest classification category. Based upon biochemical and genetic evidence, scientists have identified three domains: **domain Archaea, domain Bacteria,** and **domain Eukarya.** Both domain Archaea and domain Bacteria contain single-celled **prokaryotes,** which lack the membrane-bound nucleus and organelles found in the cells of **eukaryotes** in domain Eukarya.

Prokaryotes are structurally simple (Fig. 1.5) but metabolically complex. *Bacteria* are found almost anywhere—in the water, soil, and atmosphere, as well as on our skin and in our digestive tracts. Although some bacteria cause diseases, others are beneficial, both environmentally and commercially. For example, bacteria can be used to develop new medicines, to clean up oil spills, or to help purify water in sewage treatment plants. *Archaea* live in aquatic environments that lack oxygen or are too salty, too hot, or too acidic for most other organisms. Because these environments are similar to those of the primitive Earth, archaea represent the first cells that evolved on the planet.

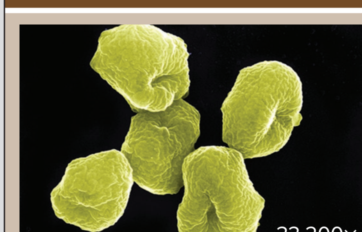
Domain Bacteria

- Prokaryotic cells of various shapes
- Adaptations to all environments
- Absorb, photosynthesize, or chemosynthesize food
- Unique chemical characteristics

Escherichia coli, a bacterium

a.

Domain Archaea



- Prokaryotic cells of various shapes
- Adaptations to extreme environments
- Absorb or chemosynthesize food
- Unique chemical characteristics

Sulfolobus, an archaean

b.

Figure 1.5 **Prokaryotic domains.** The two prokaryotic domains of life include (**a**) bacteria and (**b**) archaea. (a): ©A.B. Dowsett/SPL/Science Source; (b): ©Eye of Science/Science Source

Eukaryotic Supergroups and Kingdoms

Historically, the classification of domain Eukarya divided organisms into one of four kingdoms (Fig. 1.6). **Protists** (kingdom Protista), which comprise a very diverse group of organisms, range

Domain Eukarya: Kingdom Protista

- Algae, protozoans, slime molds, and water molds
- Complex single cell (sometimes filaments, colonies, or even multicellular)
- Absorb, photosynthesize, or ingest food

Paramecium, a single-celled protozoan

Domain Eukarya: Kingdom Fungi

- Molds, mushrooms, yeasts, and ringworms
- Mostly multicellular filaments with specialized, complex cells
- Absorb food

Amanita, a mushroom

Domain Eukarya: Kingdom Plantae

- Certain algae, mosses, ferns, conifers, and flowering plants
- Multicellular, usually with specialized tissues, containing complex cells
- Photosynthesize food

Phalaenopsis, orchid, a flowering plant

Domain Eukarya: Kingdom Animalia

- Sponges, worms, insects, fishes, frogs, turtles, birds, and mammals
- Multicellular with specialized tissues containing complex cells
- Ingest food

Vulpes, a red fox

Figure 1.6 **Kingdoms of domain Eukarya.** Historically, eukaryotes were divided into four kingdoms. However, recent genetic analyses have added a new level of classification, the supergroup (Table 1.1). (*Paramecium*): ©M. I. Walker/Science Source; (mushroom): ©Tinke Hamming/Ingram Publishing; (orchid): ©Pixtal/age fotostock; (fox): ©Fuse/Getty Images

TABLE 1.1 Eukaryotic Supergroups

Supergroup	Representative Organisms
Archaeplastida	Plants, red and green algae
SAR (stramenopiles, alveolates, and rhizaria)	Brown algae, dinoflagellates, paramecia
Excavata	Euglenoids, trypanosomes
Amoebozoa	Amoeba, slime molds
Opisthokonta	Animals, fungi, choanoflagellates

from single-celled forms to a few multicellular ones. Some use photosynthesis to manufacture food, and some must acquire their own food. Common protists include algae, the protozoans, and the water molds.

The other three kingdoms of eukaryotes in Figure 1.6 (plants, fungi, and animals) all evolved from protists. **Plants** (kingdom Plantae) are multicellular, photosynthetic organisms. Example plants include azaleas, zinnias, and pines. Among the **fungi** (kingdom Fungi) are the familiar molds and mushrooms that, along with bacteria, help decompose dead organisms. **Animals** (kingdom Animalia) are multicellular organisms that must ingest and process their food. Aardvarks, jaguars, and humans are representative animals.

Recently, the development of improved techniques in analyzing the DNA of organisms suggests that not all of the protists share the same evolutionary lineage, meaning that the evolution of the eukaryotes has occurred along several paths. A new taxonomic group, called a **supergroup,** is being developed to explain these evolutionary relationships. There are currently five supergroups for domain Eukarya (Table 1.1). However, as studies continue, the relationship and structure of these groups are being revised. We will explore the structure of the eukaryotic supergroups in more detail in Section 29.1.

Additional Levels of Classification

The other classification categories are phylum, class, order, family, genus, and species. Each classification category is more specific than the one preceding it. For example, the species within one genus share very similar characteristics, while those within the same kingdom share only general characteristics. Modern humans are the only living species in the genus *Homo,* but many different types of animals are in the animal kingdom (Table 1.2). To take another example, all species in the genus *Pisum* (pea plants) look quite similar, while the species in the plant kingdom can be quite different, as is evident when we compare grasses to trees.

Systematics helps biologists make sense out of the bewildering variety of life on Earth because organisms are classified according to their presumed evolutionary relationships. Organisms placed in the same genus are the most closely related, and those in separate domains are the most distantly related. Therefore, all eukaryotes are more closely related to one another than they are to bacteria or archaea. Similarly, all animals are more closely related to one another than they are to plants. As more is learned about evolutionary relationships among species, systematic relationships are changed. Systematists are even now making observations and

TABLE 1.2 Classification of Humans

Classification Category	Characteristics
Domain Eukarya	Cells with nuclei
Supergroup Opisthokonta	Possess cells with flagella
Kingdom Animalia	Multicellular, motile, ingestion of food
Phylum Chordata	Dorsal supporting rod and nerve cord
Class Mammalia	Hair, mammary glands
Order Primates	Adapted to climb trees
Family Hominidae	Adapted to walk erect
Genus *Homo*	Large brain, tool use
Species *Homo sapiens**	Body characteristics similar to modern humans

* To specify an organism, you must use the full binomial name, such as *Homo sapiens.*

performing experiments that will soon result in changes in the classification system adopted by this text.

Scientific Names

Taxonomists assign a binomial, or two-part name, to each species. For example, the scientific name for humans is *Homo sapiens,* and for the garden pea, *Pisum sativum.* The first word is the genus to which the species belongs, and the second word is the specific epithet, or species name. Note that both words are in italics, but only the genus name is capitalized. The genus name can be used alone to refer to a group of related species. Also, a genus can be abbreviated to a single letter if used with the species name (e.g., *P. sativum*).

Scientific names are in a common language—Latin—and biologists use them universally to avoid confusion. Common names, by contrast, tend to overlap across multiple species.

Check Your Progress 1.2

1. Describe the differences among a domain, supergroup, and kingdom.
2. List the levels of taxonomic classification from most inclusive to least inclusive.
3. Explain why scientists assign species to a hierarchical classification system (e.g., kingdom, phylum, class).

1.3 The Process of Science

Learning Outcomes

Upon completion of this section, you should be able to

1. Identify the components of the scientific method.
2. Distinguish between a theory and a hypothesis.
3. Analyze a scientific experiment and identify the hypothesis, experiment, control groups, and conclusions.

The process of science pertains to the study of biology. As you can see from Figure 1.2, the multiple stages of biological organization mean that life can be studied at a variety of levels. Some biological disciplines are cytology, the study of cells; anatomy, the study of structure; physiology, the study of function; botany, the study of plants; zoology, the study of animals; genetics, the study of heredity; and ecology, the study of the interrelationships between organisms and their environments.

Religion, aesthetics, ethics, and science are all ways in which humans seek order in the natural world. The nature of scientific inquiry differs from these other ways of knowing and learning, because the scientific process uses the **scientific method,** a standard series of steps used in gaining new knowledge that is widely accepted among scientists. The scientific method (Fig. 1.7) acts as a guideline for scientific studies. Scientists often modify or adapt the process to suit their particular field of study.

Observation

Scientists believe that nature is orderly and measurable—that natural laws, such as the law of gravity, do not change with time—and that a natural event, or *phenomenon,* can be understood more fully through **observation**—a formal way of watching the natural world.

Scientists use all of their senses in making observations. The behavior of chimpanzees can be observed through visual means, the disposition of a skunk can be observed through olfactory means, and the warning rattles of a rattlesnake provide auditory information of imminent danger. Scientists also extend the ability of their senses by using instruments; for example, the microscope enables us to see objects that could never be seen by the naked eye. Finally, scientists may expand their understanding even further by taking advantage of the knowledge and experiences of other scientists. For instance, they may look up past studies at the library or on the Internet, or they may write or speak to others who are researching similar topics.

Hypothesis

After making observations and gathering knowledge about a phenomenon, a scientist uses inductive reasoning to formulate a possible explanation. **Inductive reasoning** occurs whenever a person uses creative thinking to combine isolated facts into a cohesive whole. In some cases, a chance observation alone may help a scientist arrive at an idea.

One famous case pertains to the antibiotic penicillin, which was discovered in 1928. While examining a petri dish of bacteria that had become contaminated with the mold *Penicillium,* Alexander Flemming observed an area that was free of bacteria. Flemming, an early expert on antibacterial substances, reasoned that the mold might have been producing an antibacterial compound.

We call such a possible explanation for a natural event a **hypothesis.** A hypothesis is not merely a guess; rather, it is an informed statement that can be tested in a manner suited to the processes of science.

All of a scientist's past experiences, no matter what they might be, have the potential to influence the formation of a hypothesis. But a scientist considers only hypotheses that can be tested. Moral and religious beliefs, while very important in the lives of many people, differ between cultures and through time and may not be scientifically testable.

Predictions and Experiments

Scientists often perform an **experiment,** which is a series of procedures, to test a hypothesis. To determine how to test a hypothesis, a

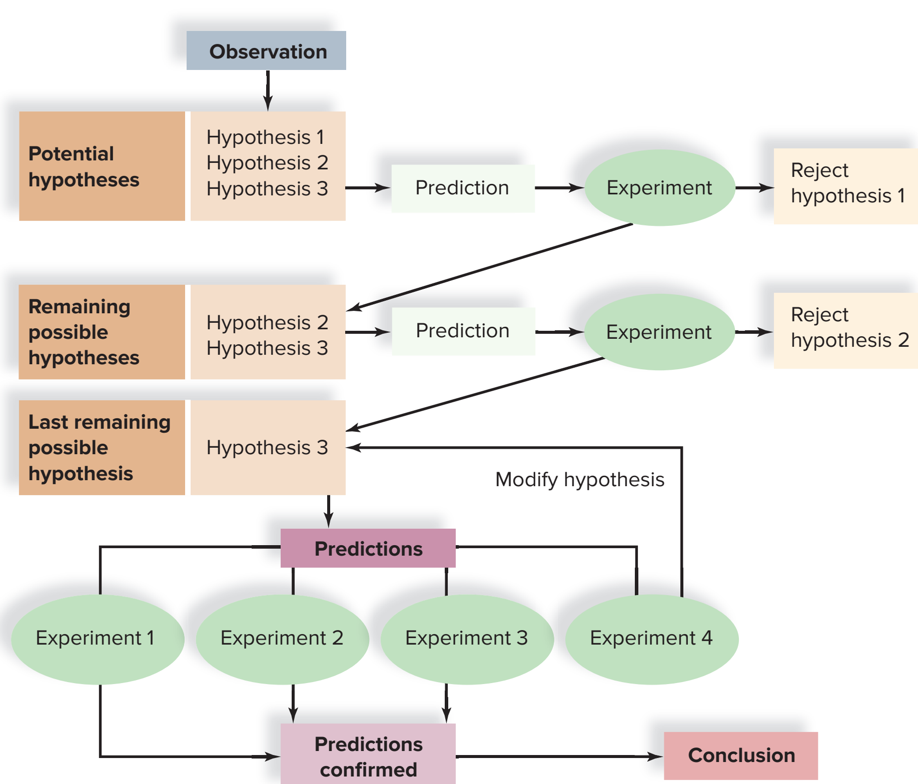


Figure 1.7 Flow diagram for the scientific method. On the basis of new and/or previous observations, a scientist formulates a hypothesis. The hypothesis is used to develop predictions to be tested by further experiments and/or observations, and new data either support or do not support the hypothesis. Following an experiment, a scientist often chooses to retest the same hypothesis or to test a related hypothesis. Conclusions from many different but related experiments may lead to the development of a scientific theory. For example, studies pertaining to development, anatomy, and fossil remains all support the theory of evolution.