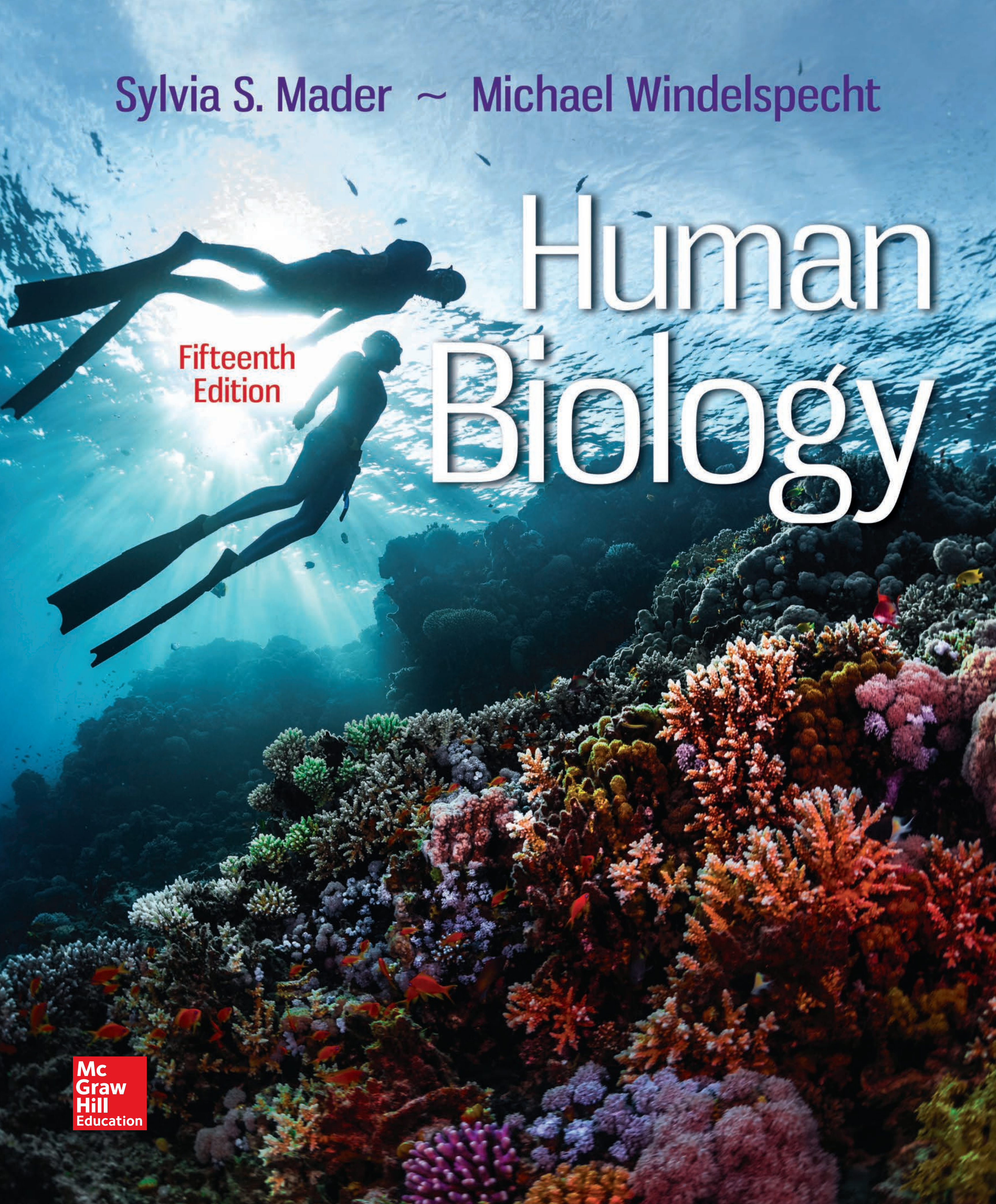
Sylvia S. Mader ~ Michael Windelspecht

Human Biology

Fifteenth Edition



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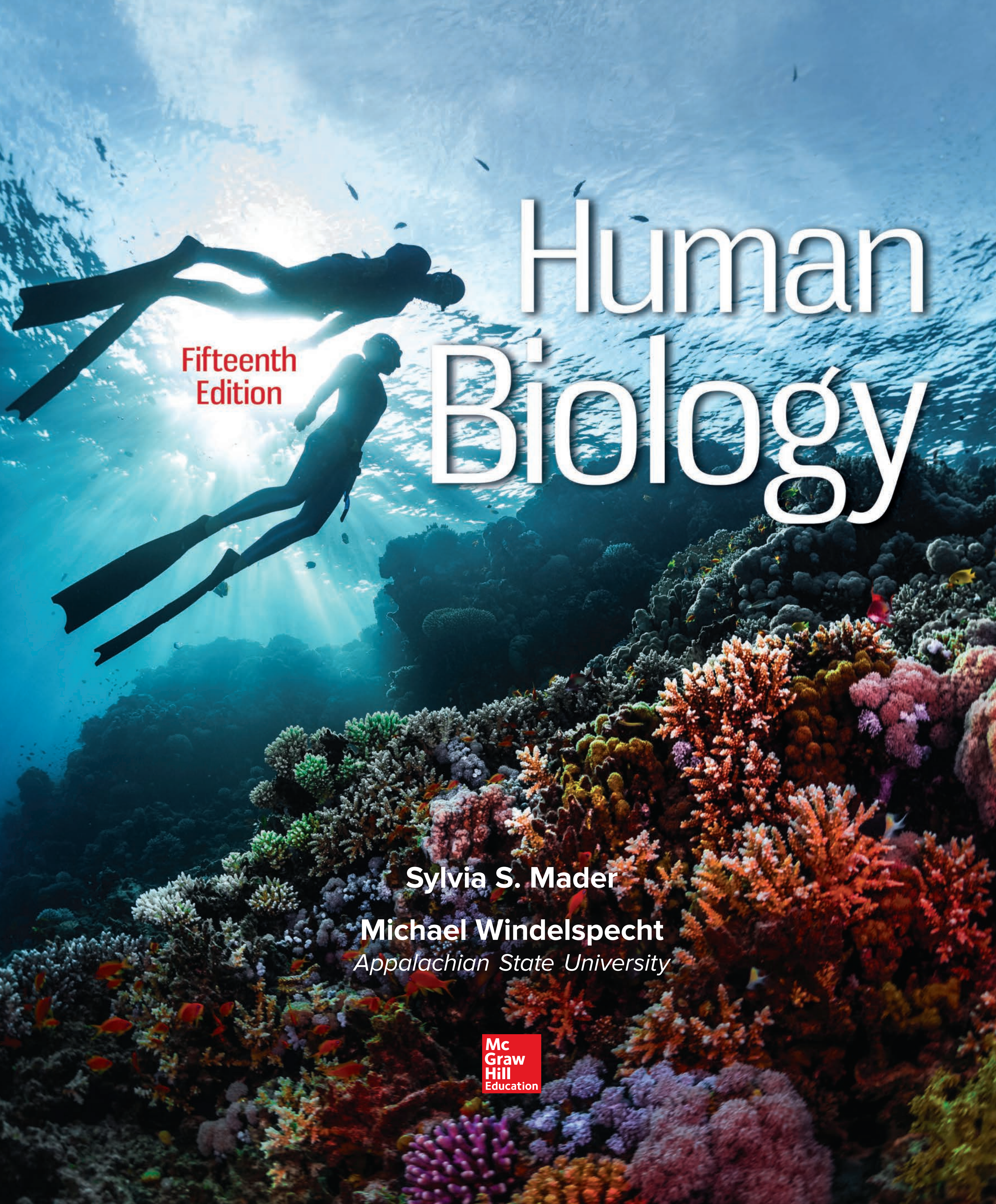

Human Biology

Fifteenth Edition

Sylvia S. Mader

Michael Windelspecht
Appalachian State University

Mc Graw Hill Education

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HUMAN BIOLOGY, FIFTEENTH EDITION

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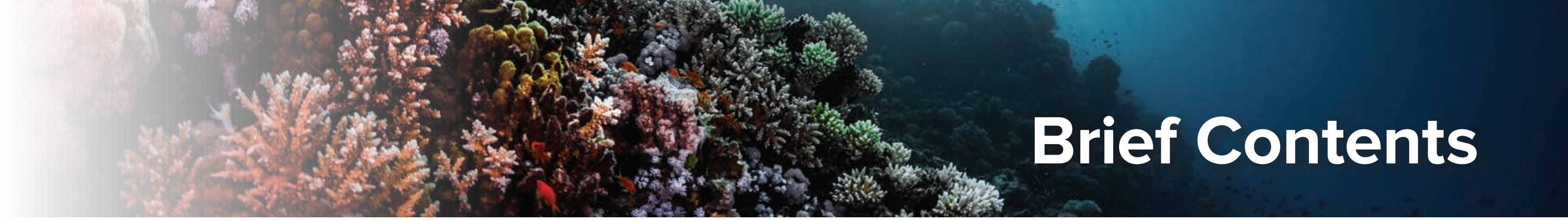
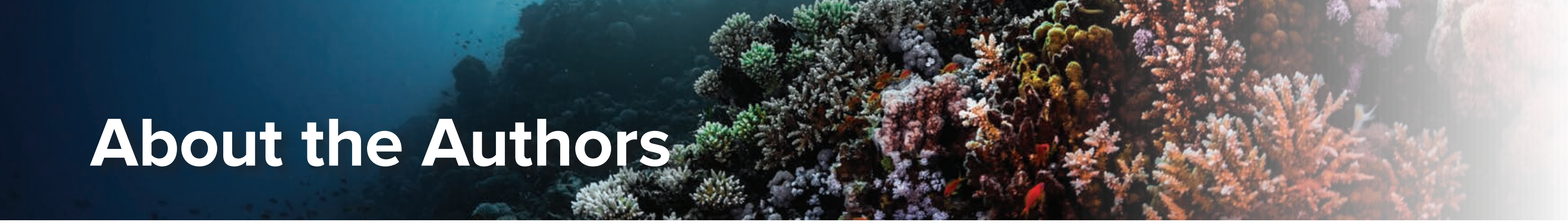


Brief Contents



About the Authors

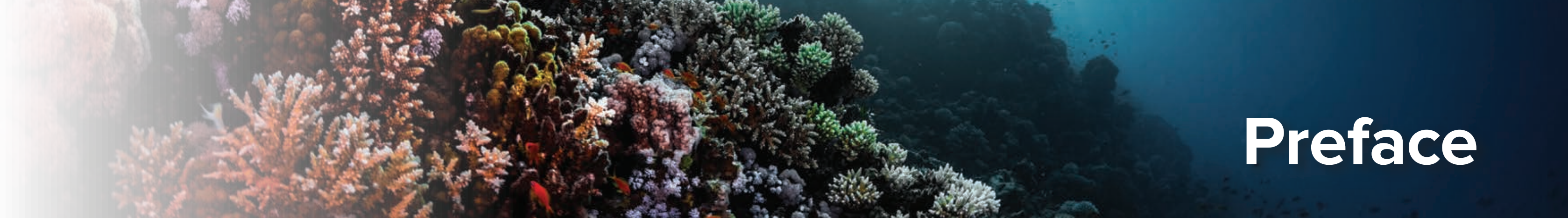
Sylvia S. Mader Sylvia S. Mader has authored several nationally recognized biology texts published by McGraw-Hill. Educated at Bryn Mawr College, Harvard University, Tufts University, and Nova Southeastern University, she holds degrees in both Biology and Education. Over the years she has taught at University 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,* that is now in its fourteenth edition. Highly acclaimed for her crisp and entertaining writing style, her books have become models for others who write in the field of biology.

Dr. Mader enjoys taking time to visit and explore the various ecosystems of the biosphere. Her several trips to the Florida Everglades and Caribbean coral reefs resulted in talks she has given to various groups around the country. She has visited the tundra in Alaska, the taiga in the Canadian Rockies, the Sonoran Desert in Arizona, and tropical rain forests in South America and Australia. A photo safari to the Serengeti in Kenya resulted in a number of photographs for her texts. She was thrilled to think of walking in Darwin's footsteps when she journeyed to the Galápagos Islands with a group of biology educators. Dr. Mader was also a member of a group of biology educators who traveled to China to meet with their Chinese counterparts and exchange ideas about the teaching of modern-day biology.

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



Preface

Goals of the Fifteenth Edition

Humans are a naturally inquisitive species. As children, we become fascinated with life at a very early age. We want to know how our bodies work, why there are differences, and similarities, between ourselves and the other children around us. In other words, at a very early age, children are acting like biologists.

In many ways, today's students in the science classroom face some of the same challenges their parents did decades ago. The abundance of new terms often overwhelms even the best prepared student, and the study of biological processes and methods of scientific thinking may convince some students that "science isn't their thing." The study of human biology creates an opportunity for teachers to instruct their students using the ultimate model organism—their own bodies. Whether this is their last science class or the first in a long career in allied health, the study of human biology is pertinent to everyone.

There are also challenges that are unique to the modern classroom. Today's students 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.

In addition, this revision of *Human Biology,* Fifteenth Edition, had the following goals:

1. **Updating** of chapter openers, featured readings, and Connections content to focus on issues and topics important to this generation of students
2. Utilization of the data from the LearnSmart adaptive learning platforms to identify content areas within the text that students demonstrated difficulty in mastering
3. Refinement of digital assets to provide a more effective assessment of learning outcomes to enable instructors in the flipped, online, and hybrid teaching environments
4. Development of a new series of videos and websites to introduce relevancy and engage students in the content

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:

- A series of new chapter openers to introduce relevancy to the chapter. The authors chose topics that would be of interest to a nonscience major, and represent what would typically be found on a major news source.
- The development of new relevancy-based videos, BioNow, that offer relevant, applied classroom resources to allow students to feel that they can actually do and learn biology themselves.

- A website, RicochetScience.com, managed by Dr. Windelspecht, that provides updates on news and stories that are interesting to nonscience majors. The Biology101 project links these resources to the major topics of the text. The site also features videos and tutorial animations to assist the students in recognizing the relevancy of what they are learning in the classroom.

- In addition, the author's website, michaelwindelspecht.com, contains videos and articles on how the *Human Biology* text may be easily adapted for use in a topics-based course, or in the hybrid, online, and flipped classroom environments.

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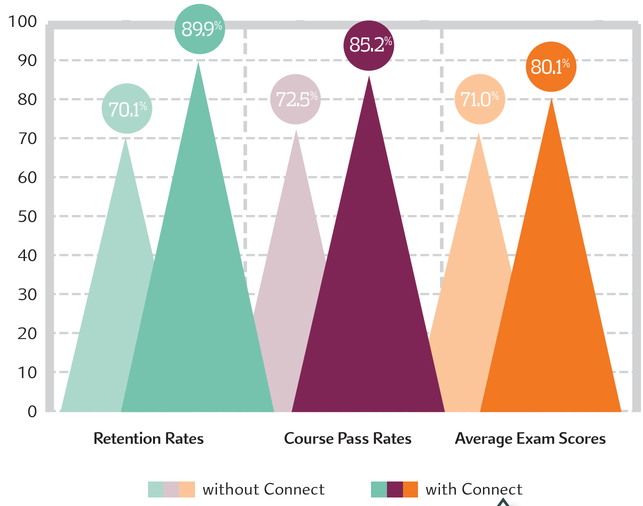

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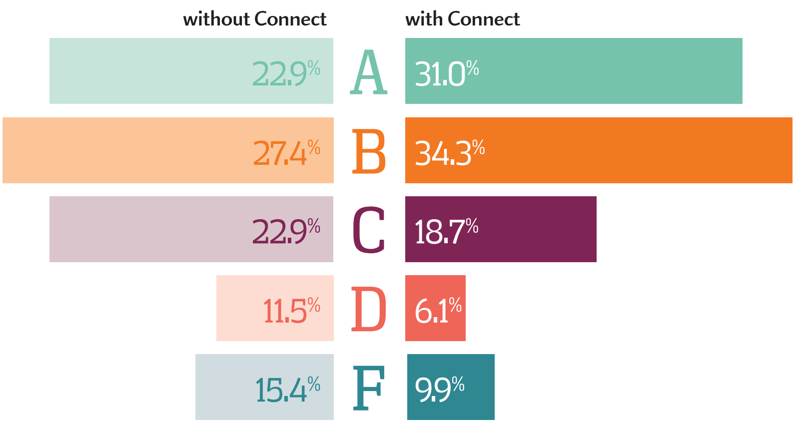

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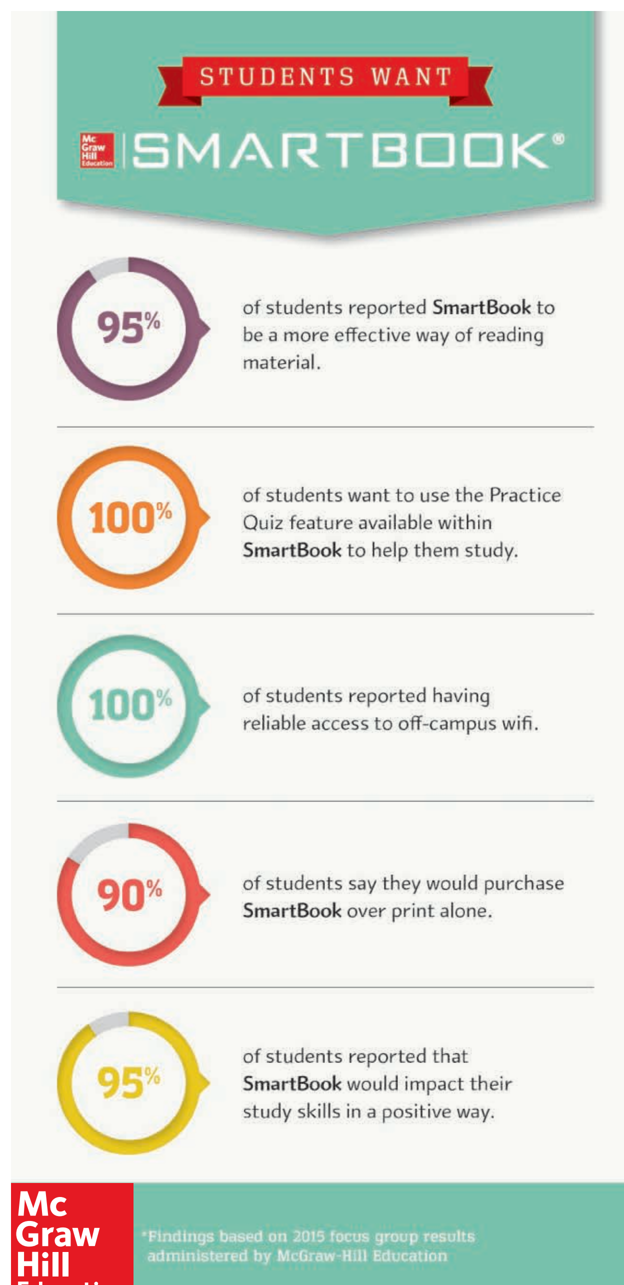

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Engaging Your Students

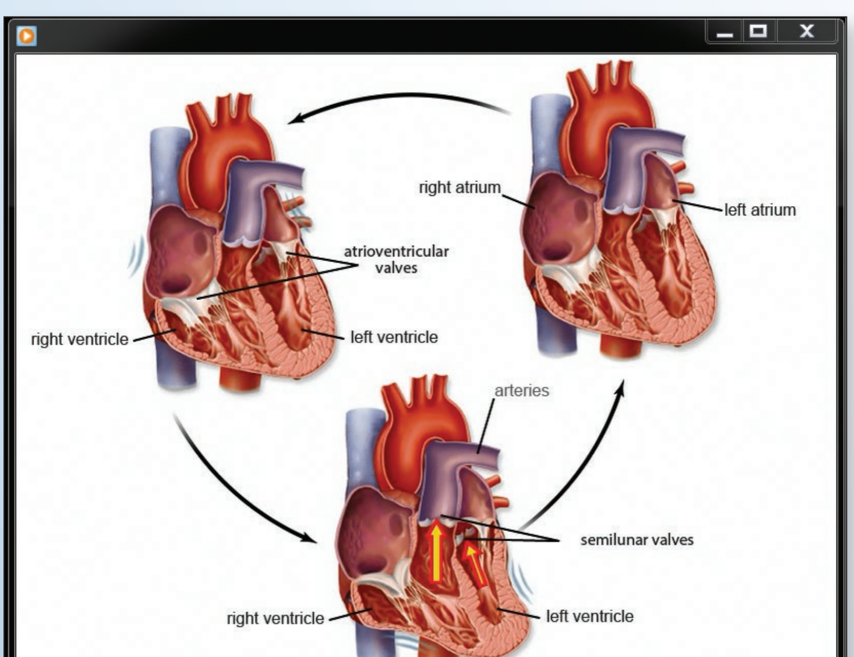
Today's science classroom relies heavily on the use of digital assets, including animations and videos, to engage students and reinforce difficult concepts. *Human Biology,* 15e, includes two resources specifically designed for the introductory science class to help you achieve these goals.

BioNow Sessions Videos

A relevant, applied approach 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 taken to use tools and techniques that any regular person could perform, so your students see the science as something they could do and understand.

A video series narrated and produced by Jason Carlson



An animation series narrated by Michael Windelspecht and produced by Ricochet Creative Productions, LLC

Tutorial Videos

The tutorials in this series were prepared to assist students in understanding some of the more difficult topics in biology. Each of the videos explores a specific figure in the text.

For students, these act as informal office hours, where they can review the most difficult concepts in the chapter at a pace which helps them learn.

Instructors of hybrid and flipped courses will find these useful as online supplements.

Readings

BIOLOGY TODAY Bioethics

BIOLOGY TODAY Health

BIOLOGY TODAY Science

Detailed List of Content Changes in *Human Biology*, Fifteenth Edition

A number of the chapters in this edition now include references and links to new BioNow relevancy videos that have been designed to show students how the science of biology applies to their everyday lives. All of these are available in the instructor and student resources section within Connect. In addition, for the digital edition of the text, many of the images and illustrations have been reworked to be compatible with the mobile environment.

In **Chapter 1: Exploring Life and Science** the discussion of levels of biological organization (Fig. 1.2) now includes a species level. The content on challenges facing science (Section 1.4) now focuses on biodiversity loss, emerging and reemerging diseases, and climate change.

Unit 1: Human Organization

Chapter 3: Cell Structure and Function has been reorganized so that the discussion of ATP occurs before the content on cellular respiration in Section 3.6. The Science feature, "Face Transplantation," in **Chapter 4: Organization and Regulation of Body Systems** has been updated to provide examples of advances in the procedure.

Unit 2: Maintenance of the Human Body

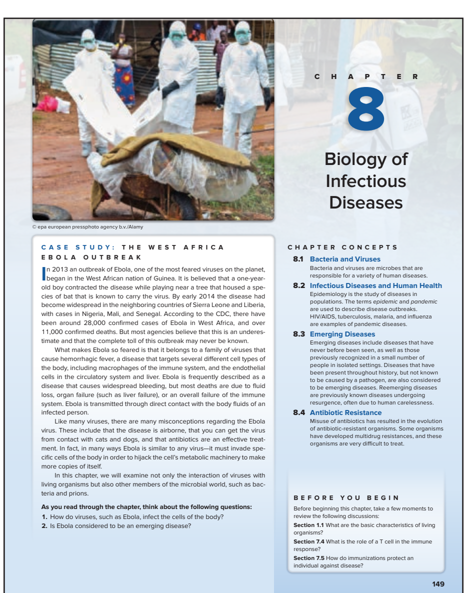
Chapter 5: Cardiovascular System: Heart and Blood Vessels contains a new Health feature on preventing cardiovascular disease. **Chapter 6: Cardiovascular System: Blood** has a new Science in Your Life box on carbon monoxide. Section 6.5 has been renamed as "Human Blood Types" to indicate the focus on the basis of blood types. **Chapter 7: The Lymphatic and Immune Systems** has new figures (Fig. 7.6) on the interaction of the adaptive defenses, and B cell clonal selection (Fig. 7.7). The Health feature on adult vaccination schedules has been updated. **Chapter 8: Biology of Infectious Diseases** has a new chapter opener on the Ebola outbreak in west Africa. This is supplemented by additional content and a new figure (Fig. 8.5) in Section 8.2. The data and graphics for HIV/AIDS (Section 8.2) has been updated. A new Health feature. "HIV Testing" has also been added. **Chapter 9: Digestive System and Nutrition** now begins with a discussion of celiac disease. The BMI discussion includes a new table of values (Table 9.3) and metric calculations. A new Health feature on the new dietary guidelines has been added to Section 9.6. In **Chapter 10: Respiratory System,** the Science feature "Artificial Lungs" now explores the extracorporeal membrane oxygenation (ECMO) and BioLung technologies. **Chapter 11: Urinary System** has a new chapter opener on kidney stones.

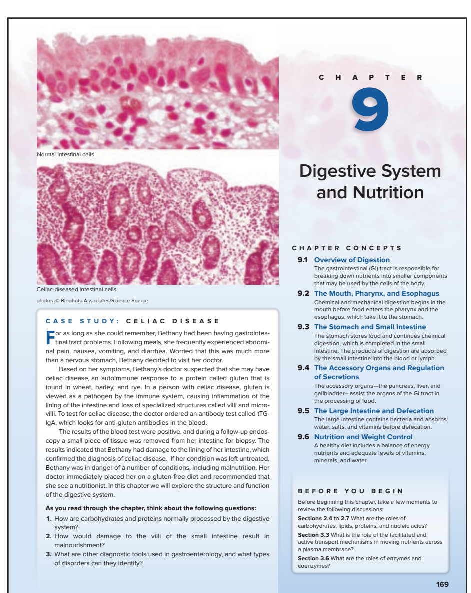
Unit 6: Human Genetics

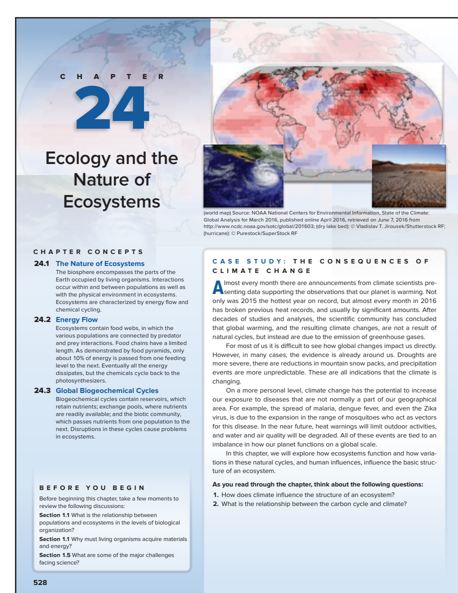
Chapter 22: DNA Biology and Technology includes new content on genome editing (CRISPR) in Section 22.3. The content on biotechnology products in plants has been updated with new examples.

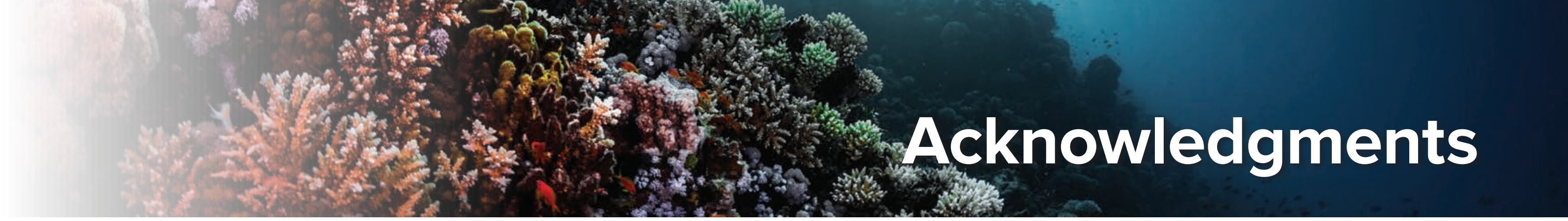
Unit 7: Human Evolution and Ecology

Chapter 23: Human Evolution begins with new material on Neandertal genes in *Homo sapiens.* Also included are a revised graph of human evolution (Fig. 23.16) and content on *Homo naledi.* **Chapter 24: Ecology and the Nature of Ecosystems** begins with a new chapter opener on the consequences of climate change. The chapter contains a new graphic of the major terrestrial biomes (Fig. 24.1). A new Bioethics feature, "The California Drought" has been added. **Chapter 25: Human Interactions with the Biosphere** now starts with a piece on the Flint water crisis.









Acknowledgments

Dr. Sylvia Mader is one of the icons of science education. Her dedication to her students, coupled to 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 emails 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 *Human Biology,* Fifteenth Edition. 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.
- My brand manager, Michelle Vogler, for her guidance and reminding me why what we do is important.
- My marketing manager, Britney Ross, and market development manager, Jenna Paleski, for placing me in contact with great instructors, on campus and virtually, throughout this process.
- The digital team of Eric Weber and Christine Carlson for helping me envision the possibilities in our new digital world.
- My content project manager, Jayne Klein, and program manager, Angie Fitzpatrick, for calmly steering this project throughout the publication process.
- Lori Hancock and Jo Johnson for the photos within this text. Biology is a visual science, and your contributions are evident on every page.
- David Hash for the design elements in this text, including one of the most beautiful textbook covers in the business.
- Dawnelle Krouse, Carey Lange, and Jane Hoover who acted as my proofreaders and copyeditor for this edition.
- Jane Peden for her behind the scenes work that keeps us all functioning.
- Inkling for providing a dynamic authoring platform, and Aptara for all of their technical assistance.

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 for all of their support. My wife and partner Sandy has never wavered in her energy and support of my projects. The natural curiosity of my children, Devin and Kayla, has provided me with the motivation to make this world a better place for everyone.

Michael Windelspecht, Ph.D.
Blowing Rock, NC

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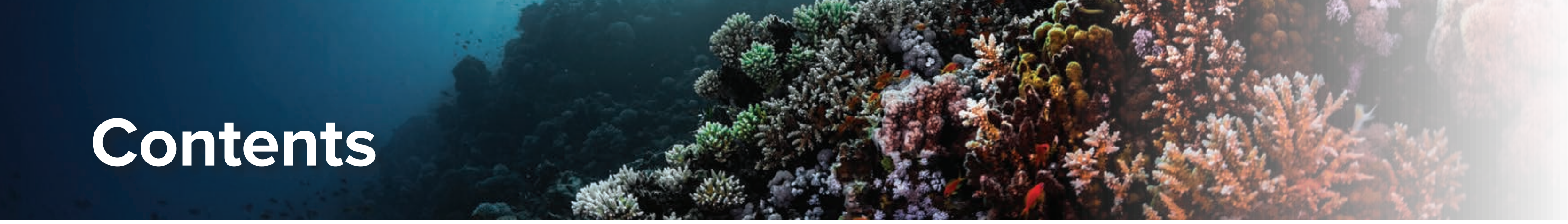

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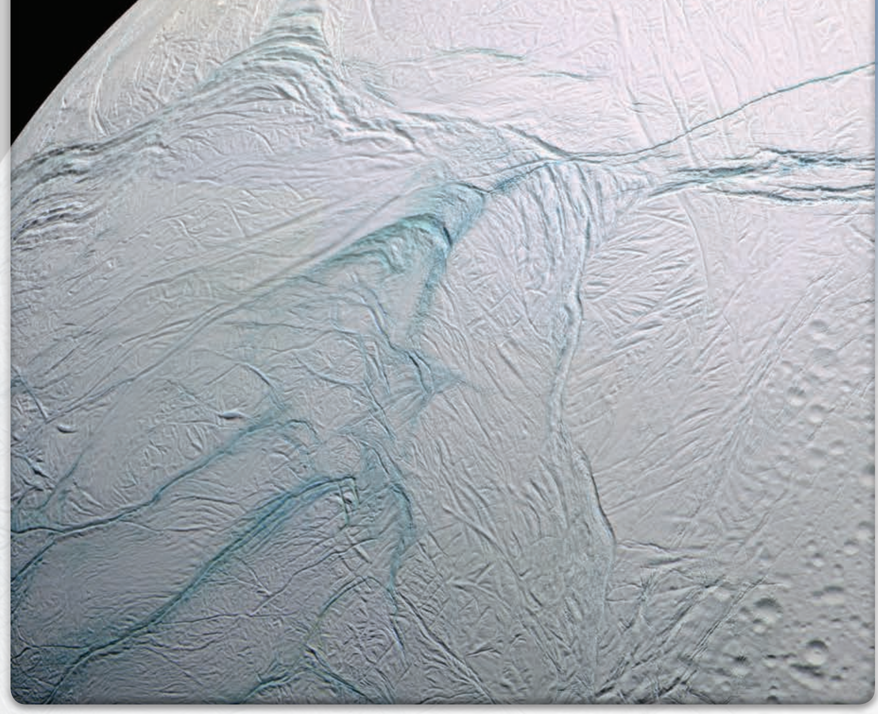

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CHAPTER

1

Exploring Life and Science

CASE STUDY: THE SEARCH FOR LIFE

What do Enceladus, Europa, Titan, Mars, and Earth all have in common? Besides being part of our solar system, they are all at the front line of our species' effort to understand the nature of life.

You may never have heard of Enceladus (shown above) or Europa, but they are both now prime candidates to harbor life outside of Earth. Enceladus is one of Saturn's moons, and Europa orbits Jupiter. Why are these moons so special? Because scientists believe that both of these moons contain water, and plenty of it. Even though Enceladus and Europa are far from the sun, the gravitational pull of their parent planets means that each of these moons may have an ocean of liquid water beneath its frozen surface. And as we will see, water has an important relationship to life.

Titan is the second-largest satellite in the solar system, larger than even our moon. Although it is in orbit around Saturn, and thus located some distance from the influence of the sun, Titan has become a focal point for the study of extraterrestrial life since the NASA space probe *Cassini-Huygens* first arrived at Saturn in 2004. *Cassini* has detected on Titan the presence of the building blocks of life, including lakes of methane and ammonia, and vast deposits of hydrogen and carbon compounds called hydrocarbons.

On Earth, scientists are exploring the extreme environments near volcanoes and deep-sea thermal vents to get a better picture of what life may have looked like under the inhospitable conditions that dominated at the time when, we now know, life first began on our planet. There is evidence that water is still present on Mars, raising the hopes that we may still find evidence of early life there.

In this chapter we will explore what it means to be alive. By looking to other areas of our solar system, we may develop a better understanding of how life first developed and our place in the universe.

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

1. What are the basic characteristics that define life?
2. What evidence would you look for on one of these moons that would tell you that life may have existed on it in the past?
3. What does it tell us if we discover life on one of these moons and it has characteristics similar to those of life on Earth? What if it is very different?

CHAPTER CONCEPTS

1.1 The Characteristics of Life
The process of evolution accounts for the diversity of living organisms and explains why all life shares the same basic characteristics.

1.2 Humans Are Related to Other Animals
Humans are eukaryotes and are further classified as vertebrate mammals in the animal kingdom.

1.3 Science as a Process
Biologists use a scientific process when they make observations and study the natural world. Data is collected, analyzed, and sent to be reviewed by the scientific community.

1.4 Challenges Facing Science
Technology is the application of scientific information. Many challenges, including climate change, the loss of biodiversity, and emerging diseases, are actively being studied by scientists.

1.1 The Characteristics of Life

LEARNING OUTCOMES

Upon completion of this section, you should be able to

1. Explain the basic characteristics that are common to all living organisms.
2. Describe the levels of organization of life.
3. Summarize how the terms *homeostasis, metabolism, development,* and *adaptation* all relate to living organisms.
4. Explain why the study of evolution is important in understanding life.

The science of **biology** is the study of living organisms and their environments. All living organisms (Fig. 1.1) share several basic characteristics. They (1) are organized, (2) acquire materials and energy, (3) are homeostatic, (4) respond to stimuli, (5) reproduce and grow, and (6) have an evolutionary history.

Life Is Organized

Figure 1.2 illustrates the levels of biological organization. Note that, at the bottom of the figure, **atoms** join together to form the **molecules** that make up a cell. A **cell** is the smallest structural and functional unit of an organism. Some organisms, such as bacteria, are single-celled organisms. Humans are *multicellular,* because they are composed of many different types of cells. A nerve cell is one of the types of cells in the human body. It has a structure suitable to conducting a nerve impulse.

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. An **organ** is made up of several types of tissues, and each organ belongs to an **organ system.** The organs of an organ system work together to accomplish a common purpose. The brain works with the spinal cord to send commands to body parts by way of nerves. **Organisms,** such as trees and humans, are a collection of organ systems.

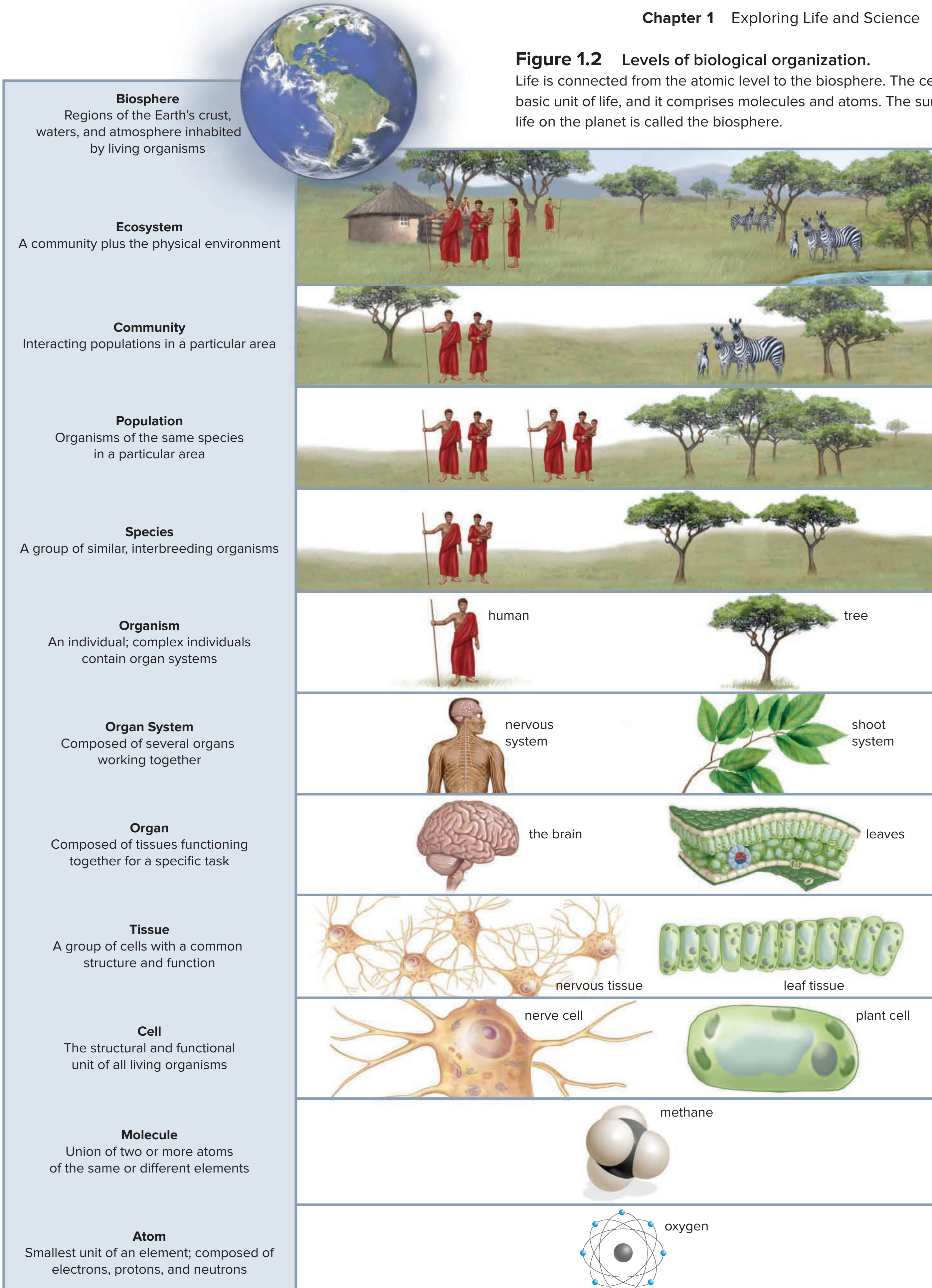
The levels of biological organization extend beyond the individual. All the members of one **species** (a group of interbreeding organisms) in a particular area belong to a **population.** A tropical grassland may have a population of zebras, acacia trees, and humans, for example. The interacting populations 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** (Fig. 1.2, *top*).

Figure 1.1 **All life shares common characteristics.**

From the simplest one-celled organisms to complex plants and animals, all life shares several basic characteristics.

(leech): © St. Bartholomews Hospital/Science Source; (mushrooms): © IT Stock/age fotostock RF; (bacteria): © Science Source; (meerkats): © Jami Tarris/Getty Images; (sunflower): © Dave Thompson/Life File/Getty RF; (*Giardia*): Source: Dr. Stan Erlandsen/CDC

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



SCIENCE IN YOUR LIFE

How many cells are in your body?

The number of cells in a human body varies depending on the size of the person and whether cells have been damaged or lost. However, most estimates suggest that there are well over 100 trillion cells in a human body.

Life Requires Materials and Energy

Humans, like all living organisms, cannot maintain their organization or carry on life's activities without an outside source of materials and energy. **Energy** is the capacity to do work. Like other animals, humans acquire materials and energy by eating food (Fig. 1.3).

Food provides nutrient molecules, which are used as building blocks or for energy. It takes energy to maintain the organization of the cell and of the organism. Some nutrient molecules are broken down completely to provide the energy necessary to convert other nutrient molecules into the parts and products of cells. The term **metabolism** describes all the chemical reactions that occur within a cell.

a.

b.

Figure 1.3 **Humans and other animals must acquire energy.**

All life, including humans (**a**) and other animals, such as this mongoose (**b**), must acquire energy to survive. The method by which organisms acquire energy is dependent on the species.

(a): © Corbis RF; (b): © Gallo Images-Dave Hamman/Getty RF

The ultimate source of energy for the majority of life on Earth is the sun. Plants, algae, and some bacteria are able to harvest the energy of the sun and convert it to chemical energy by a process called **photosynthesis.** Photosynthesis produces organic molecules, such as sugars, that serve as the basis of the food chain for many other organisms, including humans and all other animals.

Living Organisms Maintain an Internal Environment

For the metabolic pathways within a cell to function correctly, the environmental conditions of the cell must be kept within strict operating limits. The ability of a cell or an organism to maintain an internal environment that operates under specific conditions is called **homeostasis.** In humans, many of our organ systems work to maintain homeostasis. For example, human body temperature normally fluctuates slightly between 36.5 and 37.5°C (97.7 and 99.5°F) during the day. In general, the lowest temperature usually occurs between 2 A.M. and 4 A.M., and the highest usually occurs between 6 P.M. and 10 P.M. However, activity can cause the body temperature to rise, and inactivity can cause it to decline. A number of body systems, including the cardiovascular system and the nervous system, work together to maintain a constant temperature. The body's ability to maintain a normal temperature is also somewhat dependent on the external temperature. Even though we can shiver when we are cold and perspire when we are hot, we will die if the external temperature becomes overly cold or hot.

This text emphasizes how all the systems of the human body help maintain homeostasis. For example, the digestive system takes in nutrients, and the respiratory system exchanges gases with the environment. The cardiovascular system distributes nutrients and oxygen to the cells and picks up their wastes. The metabolic waste products of cells are excreted by the urinary system. The work of the nervous and endocrine systems is critical, because these systems coordinate the functions of the other systems. Throughout the text, the Connecting the Concepts feature at the end of each section will provide you with links to more information on homeostasis.

Living Organisms Respond

Homeostasis would be impossible without the body's ability to respond to stimuli. Response to external stimuli is more apparent to us, because it involves movement, as when we quickly remove a hand from a hot stove. Certain sensory receptors also detect a change in the internal environment, and then the central nervous system brings about an appropriate response. When you are startled by a loud noise, your heartbeat increases, which causes your blood pressure to increase. If blood pressure rises too high, the brain directs blood vessels to dilate, helping restore normal blood pressure.

All life responds to external stimuli, often by moving toward or away from a stimulus, such as the sight of food. Organisms may use a variety of mechanisms to move, but movement in humans and other animals is dependent on their nervous and musculoskeletal systems. The leaves of plants track the passage of the sun during the day; when a houseplant is placed near a window, its stems bend to face the sun. The movement of an animal, whether self-directed or in response to a stimulus, constitutes a large part of its *behavior*. Some behaviors help us acquire food and reproduce.

a. b.

Figure 1.4 **Growth and development define life.**
(**a**) A small acorn becomes a tree, and (**b**) following fertilization an embryo becomes a fetus by the process of growth and development.

Living Organisms Reproduce and Develop

Reproduction is a fundamental characteristic of life. Cells come into being only from preexisting cells, and all living organisms have parents. When organisms **reproduce,** they pass on their genetic information to the next generation. Following the fertilization of an egg by a sperm cell, the resulting zygote undergoes a rapid period of growth and development. This is common in most forms of life. Figure 1.4*a* illustrates that an acorn progresses to a seedling before it becomes an adult oak tree. In humans, growth occurs as the fertilized egg develops into a fetus (Fig. 1.4*b*). **Growth,** recognized by an increase in size and often in the number of cells, is a part of development. In multicellular organisms, such as humans, the term **development** is used to indicate all the changes that occur from the time the egg is fertilized until death. Therefore, it includes all the changes that occur during childhood, adolescence, and adulthood. Development also includes the repair that takes place following an injury.

The genetic information of all life is **DNA (deoxyribonucleic acid).** DNA contains the hereditary information that directs not only the structure of each cell but also its function. The information in DNA is contained within **genes,** short sequences of hereditary material that specify the instructions for a specific trait. Before reproduction occurs, DNA is replicated, so that an exact copy of each gene may be passed on to the offspring. When humans reproduce, a sperm carries genes contributed by a male into the egg, which contains genes contributed by a female. The genes direct both growth and development, so that the organism will eventually resemble the parents. Sometimes **mutations,** minor variations in these genes, can cause an organism to be better suited for its environment. These mutations are the basis of evolutionary change.

Organisms Have an Evolutionary History

Evolution is the process by which a population changes over time. The mechanism by which evolution occurs is **natural selection** (see Section 23.2). When a new variation arises that allows certain members of a population to capture more resources, these members tend to survive and have more offspring than the other, unchanged members. Therefore, each successive generation will include more members with the new variation, which represents an **adaptation** to the environment. Consider, for example, populations of humans who live at high altitudes, such as the cultures living at elevations of over 4,000 meters (m) (14,000 ft) in the Tibetan Plateau. This environment is very low in oxygen. As the Science feature "Adapting to Life at High Elevations" investigates, these populations have evolved an adaptation that reduces the amount of hemoglobin, the oxygen-carrying pigment in the blood. As the feature explains, this adaptation makes life at these altitudes possible.

Evolution, which has been going on since the origin of life and will continue as long as life exists, explains both the unity and the diversity of life. All organisms share the same characteristics of life because their ancestry can be traced to the first cell or cells. Organisms are diverse because they are adapted to different ways of life.

BIOLOGY TODAY **Science**

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.

Figure 1A
Individuals living at high elevations, such as these Tibetans, have become adapted to their environment.

Normally when 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), excess hemoglobin 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.

Because high hemoglobin levels would be a detriment to people at high elevations, it makes sense that natural selection would favor individuals who produce 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 the Tibetan 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 that data because it suggested 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 23.5). 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 now-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?

CHECK YOUR PROGRESS 1.1

1. List the basic characteristics of life.
2. Summarize the levels of biological organization.
3. Explain the relationship between adaptations and evolutionary change.

CONNECTING THE CONCEPTS

Both homeostasis and evolution are central themes in the study of biology. For more examples of homeostasis and evolution, refer to the following discussions:

Section 4.8 explains how body temperature is regulated.

Section 11.4 explores the role of the kidneys in fluid and salt homeostasis.

Section 23.3 examines the evolutionary history of humans.

1.2 Humans Are Related to Other Animals

LEARNING OUTCOMES

Upon completion of this section, you should be able to

1. Summarize the place of humans in the overall classification of living organisms.
2. Understand that humans have a cultural heritage.
3. Describe the relationship between humans and the biosphere.

Biologists classify all life as belonging to one of three **domains.** The evolutionary relationships of these domains are presented in Figure 1.5. Two of these, domain Bacteria and domain Archaea, contain prokaryotes, single-celled organisms that lack a nucleus. Organisms in the third domain, Eukarya, all contain cells that possess a nucleus. Some of these organisms are single-celled; others are multicellular. Humans are multicelled Eukarya.

Domain Eukarya is divided into one of four **kingdoms** (Fig. 1.6)—plants (Plantae), fungi (Fungi), animals (Animalia), and protists (Protista). Most organisms in kingdom Animalia are *invertebrates,* such as earthworms, insects, and mollusks. *Vertebrates* are animals that have a nerve cord protected by a vertebral column, which gives them their name. Fish, reptiles, amphibians, and birds are all vertebrates. Vertebrates with hair or fur and mammary glands are classified as *mammals*. Humans, raccoons, seals, and meerkats are examples of mammals.

Humans are most closely related to apes. We are distinguished from apes by our (1) highly developed brains, (2) completely upright stance, (3) creative language, and (4) ability to use a wide variety of tools. Humans did not evolve from apes; apes and humans share a common, apelike ancestor. Today's apes are our evolutionary cousins. Our relationship to apes is analogous to you and your first cousin being descended from your grandparents. We could not have evolved directly from our cousins, because we are contemporaries—living on Earth at the same time.

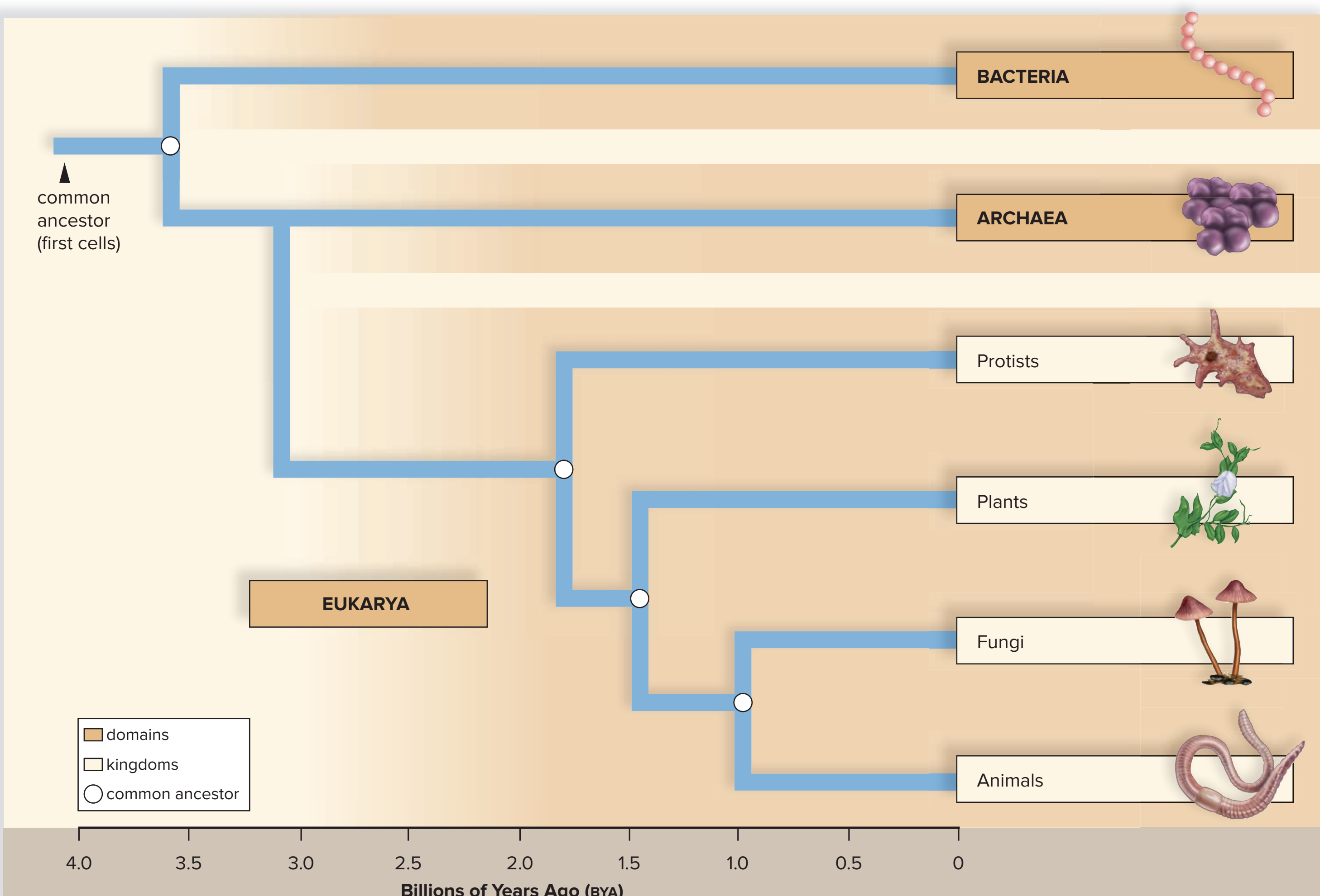


Figure 1.5 **The evolutionary relationships of the three domains of life.**
Living organisms are classified into three domains: Bacteria, Archaea, and Eukarya. The Eukarya are further divided into kingdoms (see Fig. 1.6).

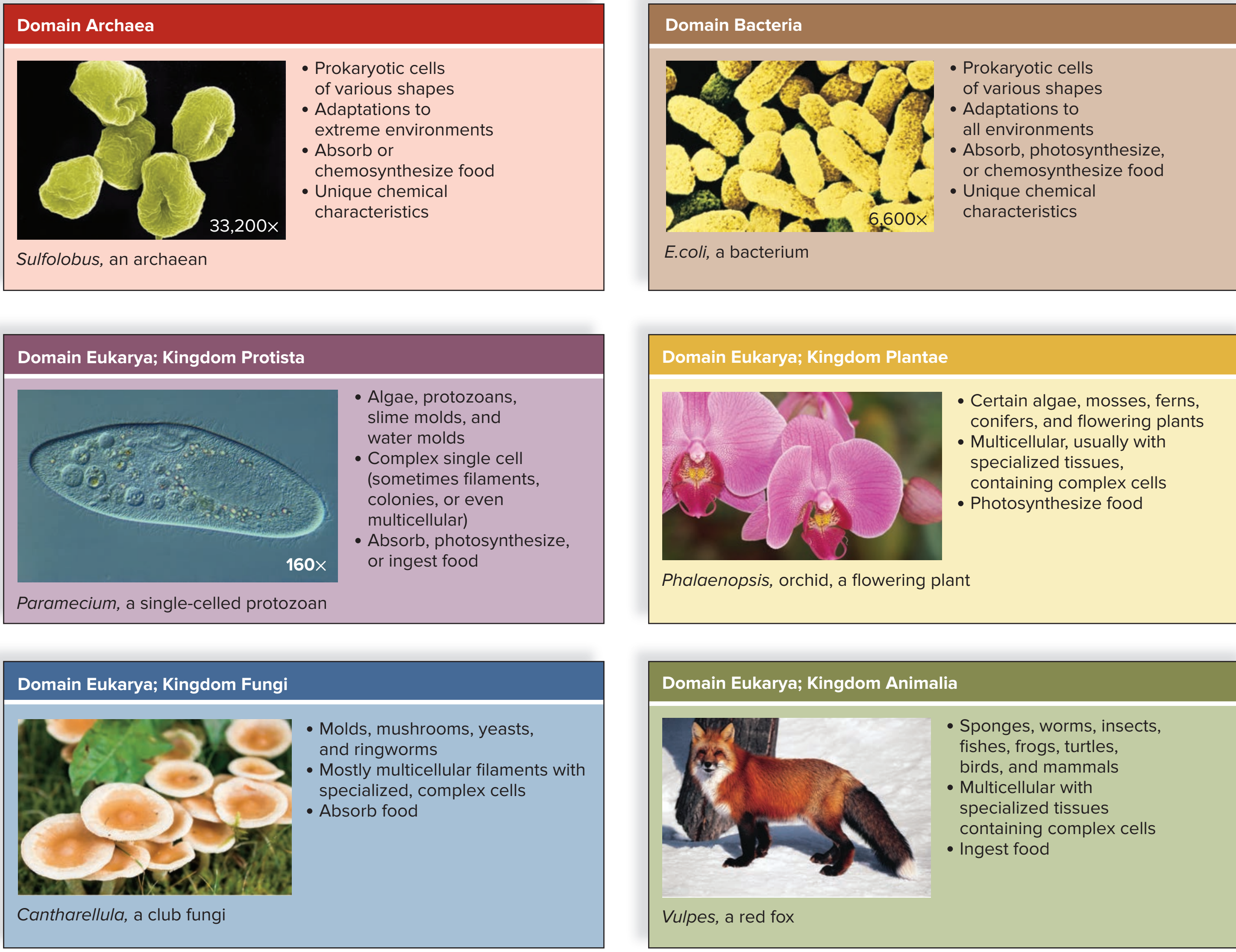


Figure 1.6 **The classification of life.**
This figure provides some of the characteristics of the organisms of each of the major domains and kingdoms of life. Humans belong to the domain Eukarya and kingdom Animalia.

Humans Have a Cultural Heritage

Humans have a cultural heritage in addition to a biological heritage. *Culture* encompasses human activities and products passed on from one generation to the next outside of direct biological inheritance. Among animals, only humans have a language that allows us to communicate information and experiences symbolically. We are born without knowledge of an accepted way to behave, but we gradually acquire this knowledge by adult instruction and the imitation of role models. Members of the previous generation pass on their beliefs, values, and skills to the next generation. Many of the skills involve tool use, which can vary from how to hunt in the wild to how to use a computer. Human skills have also produced a rich heritage in the arts and sciences. However, a society highly dependent on science and technology has its drawbacks as well. Unfortunately, this cultural development may mislead us into believing that humans are somehow not part of the natural world surrounding us.

Humans Are Members of the Biosphere

All life on Earth is part of the biosphere, the living network that spans the surface of the Earth into the atmosphere and down into the soil and seas. Although humans can raise animals and crops for food, we depend on the environment for many services. Without microorganisms that decompose, the waste we create would soon cover the Earth's surface. Some species of bacteria can clean up pollutants like heavy metals and pesticides.

Freshwater ecosystems, such as rivers and lakes, provide fish to eat, drinking water, and water to irrigate crops. Many of our crops and prescription drugs were originally derived from plants that grew naturally in an ecosystem. Some human populations around the globe still depend on wild animals as a food source. The water-holding capacity of forests prevents flooding, and the ability of forests and other ecosystems to retain soil prevents soil erosion. For many people, these forests provide a place for recreational activities like hiking and camping.

SCIENCE IN YOUR LIFE

How many humans are there?

As of 2016, it was estimated that there were over 7.4 billion humans on the planet. Each of those humans needs food, shelter, clean water and air, and materials to maintain a healthy lifestyle. We add an additional 80 million people per year—that is like adding ten New York Cities per year! This makes human population growth one of the greatest threats to the biosphere.

CHECK YOUR PROGRESS 1.2

1. Define the term *biosphere*.
2. Define *culture*.
3. Explain why humans belong to the domain Eukarya and kingdom Animalia.

CONNECTING THE CONCEPTS

To learn more about the preceding material, refer to the following discussions:

Chapter 23 examines recent developments in the study of human evolution.

Chapter 24 provides a more detailed look at ecosystems.

Chapter 25 explores how humans interact with the biosphere.

1.3 Science as a Process

LEARNING OUTCOMES

Upon completion of this section, you should be able to

1. Describe the general process of the scientific method.
2. Distinguish between a control group and an experimental group in a scientific test.
3. Recognize the importance of scientific journals in the reporting of scientific information.
4. Interpret information that is presented in a scientific graph.
5. Recognize the importance of statistical analysis to the study of science.

Science is a way of knowing about the natural world. When scientists study the natural world, they aim to be objective, rather than subjective. Objective observations are supported by factual information, whereas subjective observations involve personal judgment. For example, the fat content of a particular food would be an objective observation of a nutritional study. Reporting about the good or bad taste of the food would be a subjective observation. It is difficult to make objective observations and conclusions, because we are often influenced by our prejudices. Scientists must keep in mind that scientific conclusions can change because of new findings. New findings are often made because of recent advances in techniques or equipment.

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.

The approach of individual scientists to their work is as varied as the scientists. However, much of the scientific process is descriptive. For example, an observation of a new disease may lead a scientist to describe all the aspects of the disease, such as the environment, the age of onset, and the characteristics of the disease. Some areas of biology, such as the study of biodiversity in the ecological sciences (see Section 1.4), lend themselves more to this descriptive approach. Regardless of their area of study, most scientists spend a considerable amount of time performing a descriptive analysis of their observation before proceeding into the steps of the scientific method. Scientists often modify or adapt the process to suit their particular field of study, but for the sake of discussion it is useful to think of the scientific method as consisting of certain steps.

Start with an 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.

Observations may be made with the senses, such as sight and smell, or with instruments; for example, a microscope enables us to see objects that could never be seen by the naked eye. 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 on the Internet or at the library, or they may write or speak to others who are researching similar topics.

Develop a Hypothesis

After making observations and gathering knowledge about a phenomenon, a scientist uses inductive reasoning. **Inductive reasoning** occurs whenever a person uses creative thinking to combine isolated facts into a cohesive whole. Chance alone can help a scientist arrive at an idea. The most famous case pertains to the antibiotic penicillin, which was discovered in 1928. While examining a petri dish of bacteria that had accidentally become contaminated with the mold *Penicillium*, Alexander Fleming observed an area around the mold that was free of bacteria. Fleming had