INQUIRY INTO LIFE

SYLVIA S. MADER
MICHAEL WINDELSPECHT

FIFTEENTH EDITION

Mc Graw 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,* which is now in its fifteenth 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 foot steps 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.

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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.

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

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 forty 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.

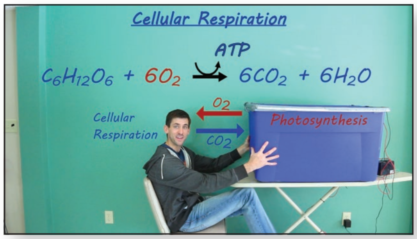
The front cover of this text was chosen to indicate not only that humans are the stewards of the planet, but also that we have interactions with almost all of the life in the biosphere. It is important that we know not only why we are different, but how we are the same as the species we share the planet 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.

In addition to the evolution of the introductory biology curriculum, students and instructors are increasingly requesting digital resources to utilize as learning resources. McGraw-Hill Education has long been an innovator in the development of digital resources, and this text, and its authors, are at the forefront of the integration of these technologies into the science classroom.

The authors of the text identified several goals that guided them through the revision of *Inquiry into Life,* Fifteenth Edition:

1. updating of chapter openers and the Science in Your Life features to focus on issues and topics important in a nonscience majors classroom
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. For more on these, see page v.
- A website, RicochetScience.com, managed by the author, 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.

Ricochet Science™

Engaging Students

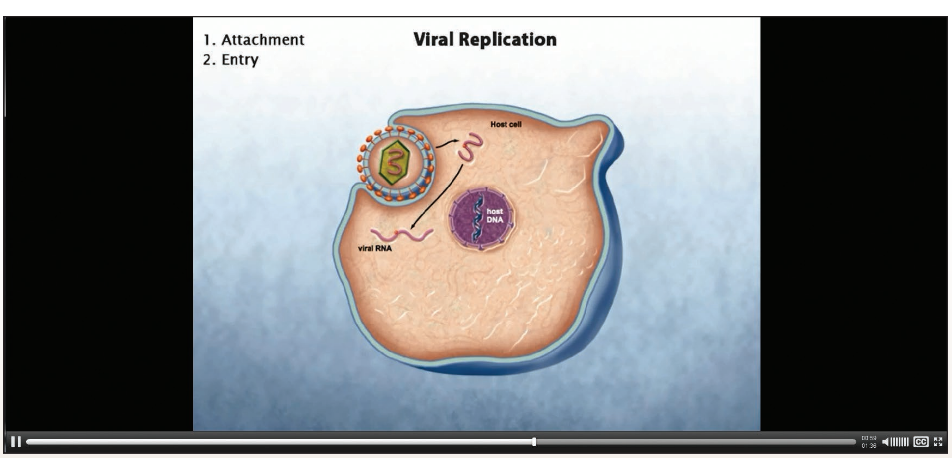
Today's science classroom relies heavily on the use of digital assets, including animations and videos, to engage students and reinforce difficult concepts. *Inquiry,* 15e, includes two resources specifically designed for the introductory science class to help you achieve these goals.

BioNow 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 Mader-series author Jason Carlson

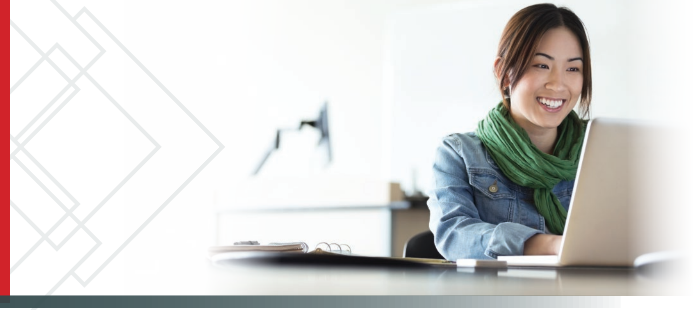


Tutorial Videos

The author, Michael Windelspecht, has prepared a series of tutorial videos to help students understand some of the more difficult topics in each chapter. Each video explores a specific figure in the text. During the video, important terms and processes are called out, allowing you to focus on the key aspects of the figure.

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.

Required=Results



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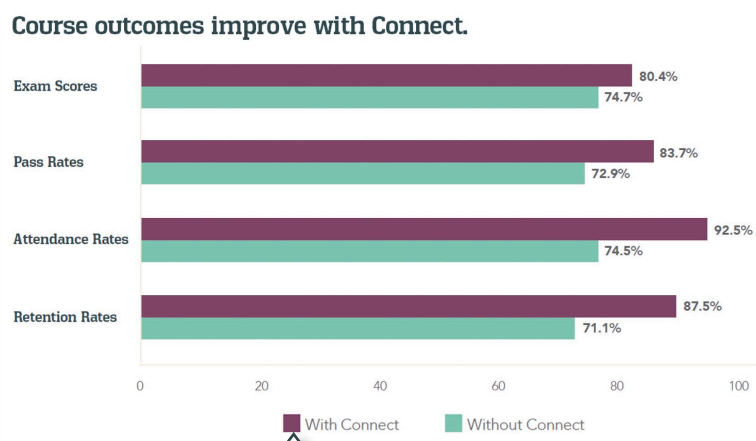

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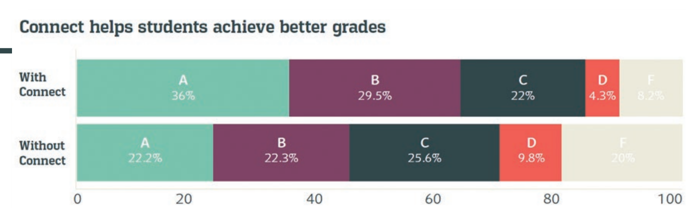

Based on McGraw-Hill Education Connect Effectiveness Study 2013

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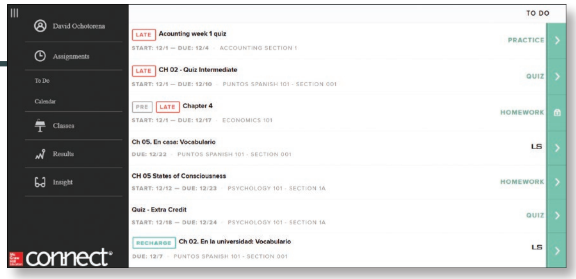

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*Findings based on a 2015 focus group survey at Pellissippi State Community College administered by McGraw-Hill Education

Detailed List of Content Changes in *Inquiry into Life*, Fifteenth Edition

Every chapter now includes links in the end-of-chapter material to the new BioNow relevancy videos. All of these are available in the instructor and student resources section within Connect.

Chapter 1: The Study of Life has been reorganized to provide a briefer overview of biology as a science. The content on the scientific process (section 1.3) has been reworked with new examples, and a new section (1.4) has been added that explores some of the major challenges facing science.

Unit 1: Cell Biology

Chapter 2: The Molecules of Cells contains a new feature, "Japan's Nuclear Crisis," that explores the fate of isotopes. **Chapter 3: Cell Structure and Function** is an expanded discussion of the principles of microscopy. The chapter opener for **Chapter 5: Cell Division** now focuses on Angelina Jolie. The section on the control of the cell cycle (5.3) now includes an expanded discussion and new figures of the effects of mutation. The Bioethical feature, "Genetic Testing for Cancer Genes," is now located in this chapter. **Chapter 6: Metabolism: Energy and Enzymes** contains new content on the function of ATP (6.2). **Chapter 7: Cellular Respiration** now explains why ATP yields rarely reach theoretical values.

Unit 2: Plant Biology

Chapter 8: Photosynthesis contains an expanded discussion of how algae may be used to produce biofuel. **Chapter 9: Plant Organization and Function** has been reorganized (sections 9.1 and 9.2) so that it follows the biological levels of organization. The chapter opener now explores the importance of the neem tree and biodiversity. The content on monocots and dicots (section 9.3) now includes differences in pollen types. **Chapter 10: Plant Reproduction and Responses** has a revised feature on pollinators that discusses the different types of plant pollinators. A new feature on the safety of genetically-modified plants has been added to section 10.3.

Unit 3: Maintenance of the Human Body

Chapter 11: Human Organization now features artist Taylor Swift in the opener. **Chapter 12: Cardiovascular System** begins with a discussion of hypertension in young adults. **Chapter 13: Lymphatic and Immune Systems** contains a new diagram on B cell clonal selection (Fig. 13.5) **Chapter 14: Digestive System and Nutrition** now contains the formula for BMI calculations and a new figure (Fig. 14.16) on the lipid content of selected fats and oils. **Chapter 15: Respiratory System** includes a new figure on Boyle's Law (Fig. 15.7) and a new Health feature on the safety of e-cigs.

Unit 4: Integration and Control of the Human Body

Chapter 17: Nervous System contains an updated PET scan (Fig. 17.19) on the effects of cocaine on the brain. **Chapter 18: Senses** has a new opener on LASIK surgery. **Chapter 19: Musculoskeletal System** contains a new figure (Fig. 19.11) on the types of movement associated with synovial joints and a new feature on the discovery of Botox®. **Chapter 20: Endocrine System** begins with a new article on diabetes in young adults.

Unit 5: Continuance of the Species

Chapter 21: Reproductive System starts with new content on IVF and the "three-parent" baby, and the content on emergency contraception (section 21.4) has been expanded. A new feature on the challenges of developing a HUV vaccine is included. **Chapter 22: Development and Aging** now begins with a discussion of the *FOX03A* gene and aging. **Chapter 23: Patterns of Gene Inheritance** opens with an article on the genetics of phenylketonuria. The traits used in the discussion of monohydrid and dihybrid crosses have been changed. **Chapter 24: Chromosomal Basis of Inheritance** contains a new figure on karyotypes (Fig. 24.7). **Chapter 25: DNA Structure and Gene Expression** has a new figure as an overview of DNA replication (Fig. 25.4). The content on mutations in cell cycle regulating proteins has been moved to Chapter 5. **Chapter 26: Biotechnology and Genomics** starts with a new essay on producing insulin using biotechnology, and includes a featured reading on reproductive and therapeutic cloning.

Unit 6: Evolution and Diversity

The opener for **Chapter 27: Evolution of Life** now contains references to resistance in *Shigella.* The geologic time scale (Table 27.1) has been updated to make it more useful for students. **Chapter 28: Microbiology** now begins with a look at the 2014–2015 Ebola outbreak in Africa. A new feature on DIY Biology has been added. **Chapter 29: Protists and Fungi** has a new opener on *Naegleria fowleri.* The content on protists in section 29.1 is now arranged by supergroups. Section 29.2 now contains more information on the evolutionary relationships of the fungi **Chapter 30: Plants** begins with an essay on the source of coal. Table 30.1 has been updated with more differences between monocots and eudicots. **Chapter 31: Animals: The Invertebrates** has a new figure on the general features of animals (Fig. 31.1). **Chapter 32: Animals: Chordates and Vertebrates** begins with

a look at canine evolution. The content on differences in vertebrate circulatory pathways has been made into a separate figure (Fig. 32.8). The content on human evolution in section 32.4 has been reworked to reflect new discoveries of human ancestors (Fig. 32.17) and a new diagram of human migration from Africa (Fig. 32.19). Material on Denisovans has been added to section 32.5.

Unit 7: Behavior and Ecology

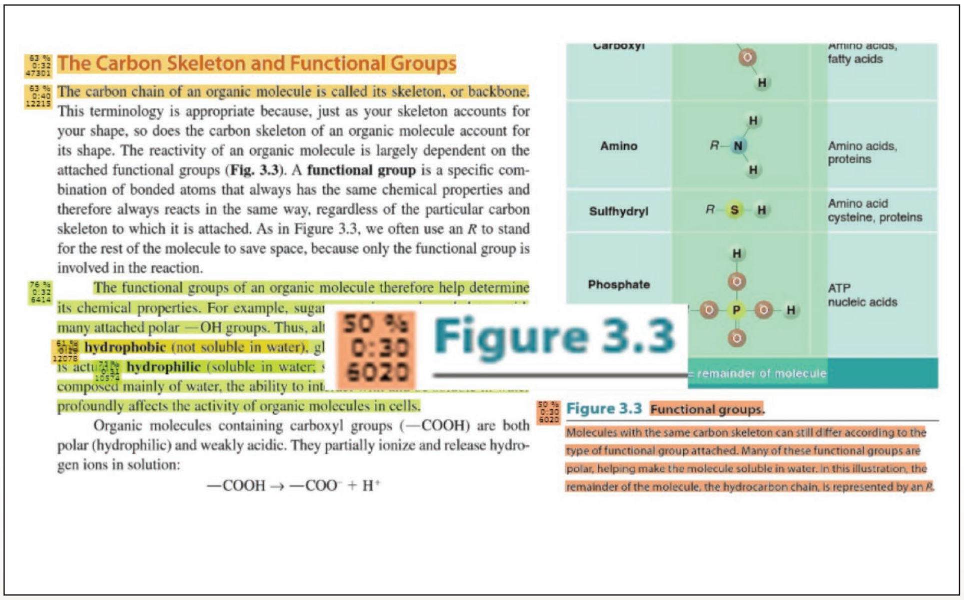
Chapter 33: Behavioral Ecology has a new feature on epigenetics and twin behavior studies. **Chapter 34: Population and Community Ecology** has a new graph on predator-prey cycles (Fig. 34.10). **Chapter 35: Nature of Ecosystems** now starts with an essay on the wolves of Yellowstone park. The chapter has a new feature on the California droughts and aquifers. In **Chapter 36: Major Ecosystems of the Biosphere,** the section on aquatic ecosystems (section 36.3) now contains a feature on the fate of prescription medicine. **Chapter 37: Conservation Biology** contains a new diagram on the number of catalogued species (Fig. 37.1)

Identifying Content to be Revised: Heat Maps

This edition of *Inquiry* is the fourth textbook in the Mader series which has identified content areas for revision by analyzing the data derived from the LearnSmart platform.

The premise is very straightforward. Students don't know what they don't know—but LearnSmart does. By compiling data from all of the probes answered by all of the students, and then overlaying that data on the text, we are able to visualize areas of content where the students are having problems.

The authors were able to use this information to not only identify areas of the text that the students were having problems with, but also areas that needed additional digital resources, such as tutorials and new Connect questions.



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 *Inquiry into Life 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, Chris Loewenberg, for his guidance and reminding me why what we do is important.
- My marketing manager, Chris Ho, 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, April Southwood, 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 and Debbie Budde-Bandy who acted as my proofreaders and copyeditors for this edition.
- Jane Peden for her behind the scenes work that keeps us all functioning.
- Inkling for finally giving me the authoring platform I have been asking for, and Aptara for all of their technical assistance.

Who I am, as an educator and an author, is a direct reflection of what I have learned from my students. Education is a mutualistic relationship, and it is my honest opinion that while I am a teacher, both my professional and personal life have been enriched by interactions with my students. They have encouraged me to learn more, teach better, and never stop questioning the world around me.

Last, but never least, I want to acknowledge my wife, Sandra. You have never wavered in your energy and support of my projects. To my children, Devin and Kayla, your natural curiosity of the world we live in gives me the energy to want to make the world a better place.

Michael Windelspecht, Ph.D.
Blowing Rock, NC

Ancillary Authors

Appendix Answer Key: Betsy Harris, *Appalachian State University;* **SmartBook:** Krissy Johnson and Alex James, *Ricochet Creative Productions;* Patrick Galliart, *North Iowa Area Community College;* **Connect Question Bank:** Alex James, *Ricochet Creative Productions;* **Test Bank:** Dave Cox, *Lincoln Land Community College;* **Lecture Outlines and Instructor's Manual:** Dan Matusiak, *St. Charles Community College*.

Brief Contents

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1 The Study of Life

CHAPTER OUTLINE

CASE STUDY The Search for Life

You may never have heard of Enceladus or Europa, but they are both at the frontline of our species' effort to understand the nature of life. 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. While both Enceladus and Europa are far from the sun, the gravitational pull of their parent planets means that beneath the frozen surface of both of these moons are oceans of liquid water. And as we will see, water has an important relationship with life.

At other locations in our solar system, scientists are looking for evidence of the chemicals that act as the building blocks of life. For example on Titan, a moon of Saturn, NASA's Cassini-Huygens space probe has detected the presence of these building blocks, including lakes of methane and ammonia, and vast deposits of hydrogen and carbon compounds called hydrocarbons.

Even more recently, the Rosetta space probe, launched by the ESA, completed its 10 year mission to land a probe on the surface of a comet. One of the most important aspects of this mission is to determine whether the chemical composition of comets includes the organic building blocks of life. NASA has recently announced missions to Europa and Mars that will continue the search for signs of life in our solar system. The information obtained from these missions will help us better understand how life originated on our planet.

In this chapter, we are going to explore what it means to be alive, and some of the general characteristics that are shared by all living organisms on our planet.

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 or Mars that would tell you that life may have existed on them 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?

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, and humans are a part of it. 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 giant sequoia trees that can reach heights of 100 meters (m) or more (Fig. 1.1).

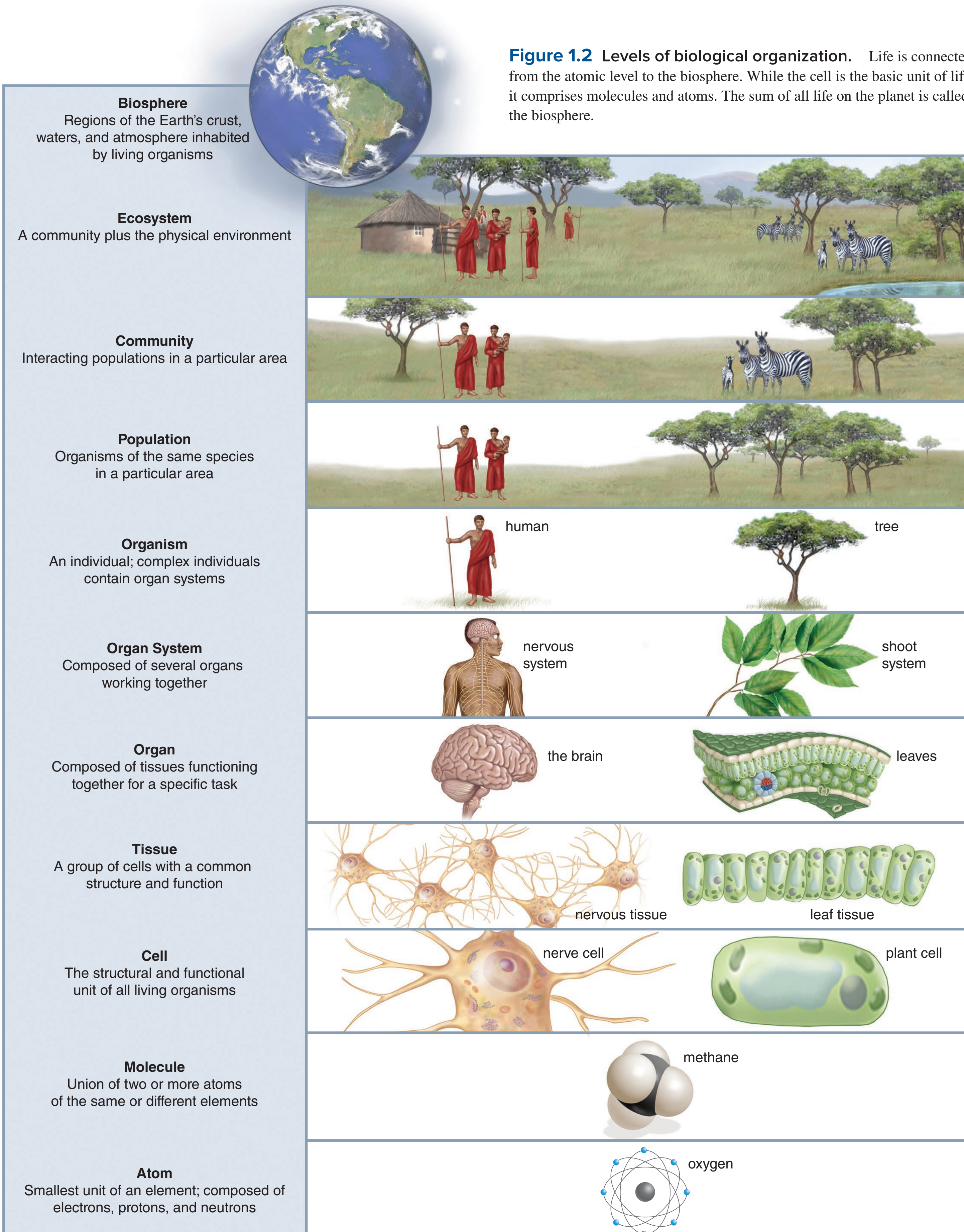
The diversity of life seems overwhelming, and yet all living organisms have certain characteristics in common. Taken together, these characteristics give us insight into the nature of life and help us distinguish living organisms from nonliving things. All life generally shares the following characteristics (1) is organized, (2) requires materials and energy, (3) has the ability to reproduce and develop, (4) responds to stimuli, (5) is homeostatic, and (6) has the capacity to adapt to their environment. In the next sections we 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 **molecules,** such as DNA molecules that occur within cells. A **cell** is

Figure 1.1 Life on planet 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.

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 comprises molecules and atoms. The sum of all life on the planet is called the biosphere.



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. Complex 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.**

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 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), 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.

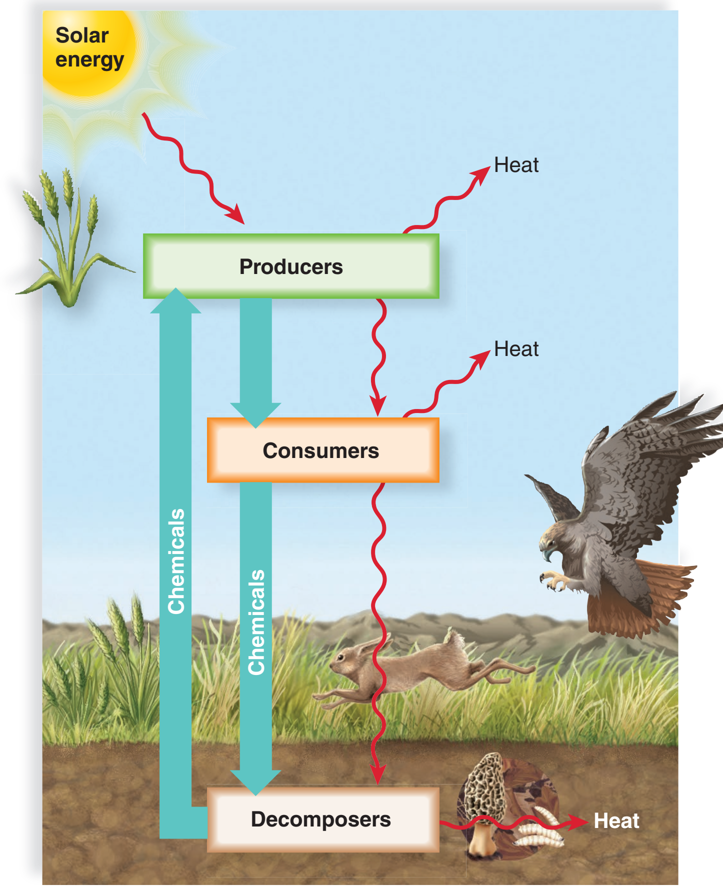


Figure 1.3 Chemical cycling and energy flow in an ecosystem. In an ecosystem, chemical cycling (aqua arrows) and energy flow (red arrows) begin when plants use solar energy and inorganic nutrients to produce their own food. Chemicals and energy are passed from one population to another in a food chain. 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.

Living Organisms Reproduce and Develop

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

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.

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 all 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.

Living Organisms Respond to Stimuli

Organisms respond to external stimuli, often by moving toward or away from a stimulus, such as the smell of food. Right now, your eyes and ears are receiving stimuli from the external environment. 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.

Living Organisms Are Homeostatic

Homeostasis means "staying the same." Actually, the internal environment of an organism stays *relatively* constant. 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.

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.

Organisms Have the Capacity 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 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.

SCIENCE IN YOUR LIFE ▶ SCIENTIFIC INQUIRY

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 that data since it 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 chapter 32). 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?

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.

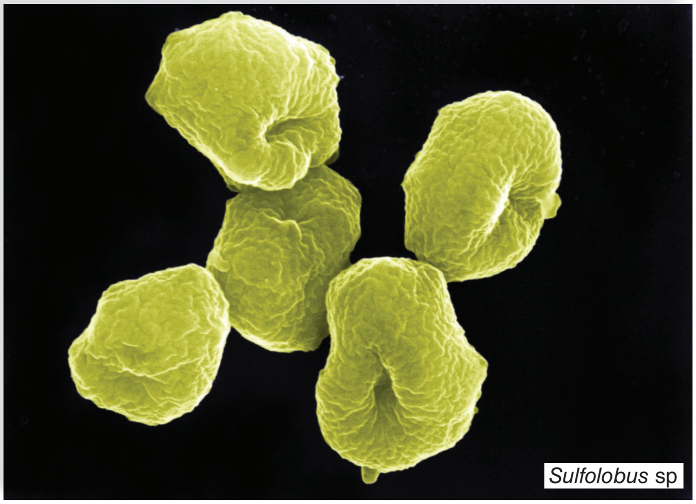
Because life is so diverse, it is helpful to group organisms into categories. **Taxonomy** is the discipline of identifying and grouping organisms according to certain rules. Taxonomy makes sense out of the bewildering variety of life on Earth and is meant to provide valuable insight into evolution. **Systematics** is the study of the evolutionary relationships between organisms. 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** (Fig. 1.5). Both domain Archaea and domain Bacteria

DOMAIN ARCHAEA

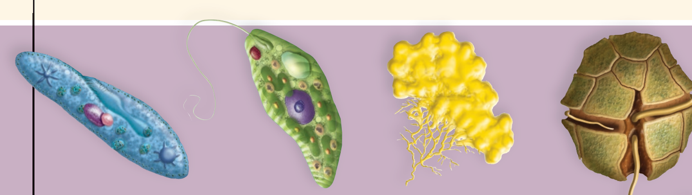
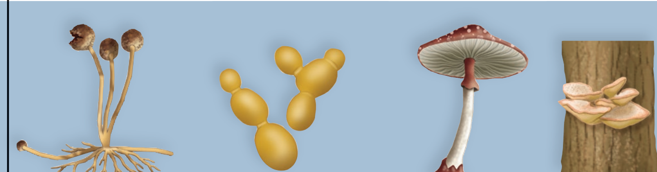


a. Archaea are capable of living in extreme environments. 33,200×

DOMAIN BACTERIA

b. Bacteria are found nearly everywhere. 6,600×

DOMAIN EUKARYA

Kingdom	Organization	Type of Nutrition	Representative Organisms	
Protista	Complex single cell, some multicellular	Absorb, photosynthesize, or ingest food	 paramecium, euglenoid, slime mold, dinoflagellate	Protozoans, algae, water molds, and slime molds
Fungi	Some single-celled, most multicellular filamentous forms with specialized complex cells	Absorb food	 black bread mold, yeast, mushroom, bracket fungus	Molds, yeasts, and mushrooms
Plantae	Multicellular form with specialized complex cells	Photosynthesize food	 moss, fern, pine tree, nonwoody flowering plant	Mosses, ferns, nonwoody and woody flowering plants
Animalia	Multicellular form with specialized complex cells	Ingest food	 sea star, earthworm, finch, human	Invertebrates, fishes, reptiles, amphibians, birds, and mammals

c. Eukaryotes are divided into four kingdoms.

Figure 1.5 The three domains of life. Archaea (**a**) and bacteria (**b**) are both prokaryotes but are so biochemically different that they are not believed to be closely related. **c.** Eukaryotes are biochemically similar but structurally dissimilar. Therefore, they have been categorized into four kingdoms. Many protists are single-celled, but the other three kingdoms are characterized by multicellular forms.

contain single-celled **prokaryotes,** which lack the membrane-bound nucleus found in the cells of **eukaryotes** in domain Eukarya. The genes of eukaryotes are found in the nucleus.

Prokaryotes are structurally simple (Fig. 1.5*a, b*) but metabolically complex. The *Archaea* live in aquatic environments that lack oxygen or are too salty, too hot, or too acidic for most other organisms. Since these environments are similar to those of the primitive Earth, archaea represent the first cells that evolved on the planet. *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.

Kingdoms

Systematists are in the process of deciding how to categorize archaea and bacteria into kingdoms. The *eukaryotes* are currently classified into at least four kingdoms with which you may be familiar (Fig. 1.5*c*). **Protists** (kingdom Protista) are primarily single-celled organisms, but there are a few multicellular species. Some can make their own food (photosynthesizers), while others must ingest their food. Because of the great diversity among protists, however, the Protista have been split into various *supergroups* to more accurately represent their evolutionary relationships. Among the **fungi** (kingdom Fungi) are the familiar molds and mushrooms that help decompose dead organisms. **Plants** (kingdom Plantae) are well known as multicellular photosynthesizers, while **animals** (kingdom Animalia) are multicellular and ingest their food.

Other Categories

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

TABLE 1.1 Classification of Humans

Classification Category	Characteristics
Domain Eukarya	Cells with nuclei
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*.

Scientific Names

Taxonomists assign a binomial, or two-part name, to each species. For example, the scientific name for human beings 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. Recognize the main criteria for classification of organisms into domains and kingdoms.
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 environment.

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. 1.6) 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 scientist uses deductive reasoning. **Deductive reasoning** involves "if, then" logic. In designing the experiment, the scientist

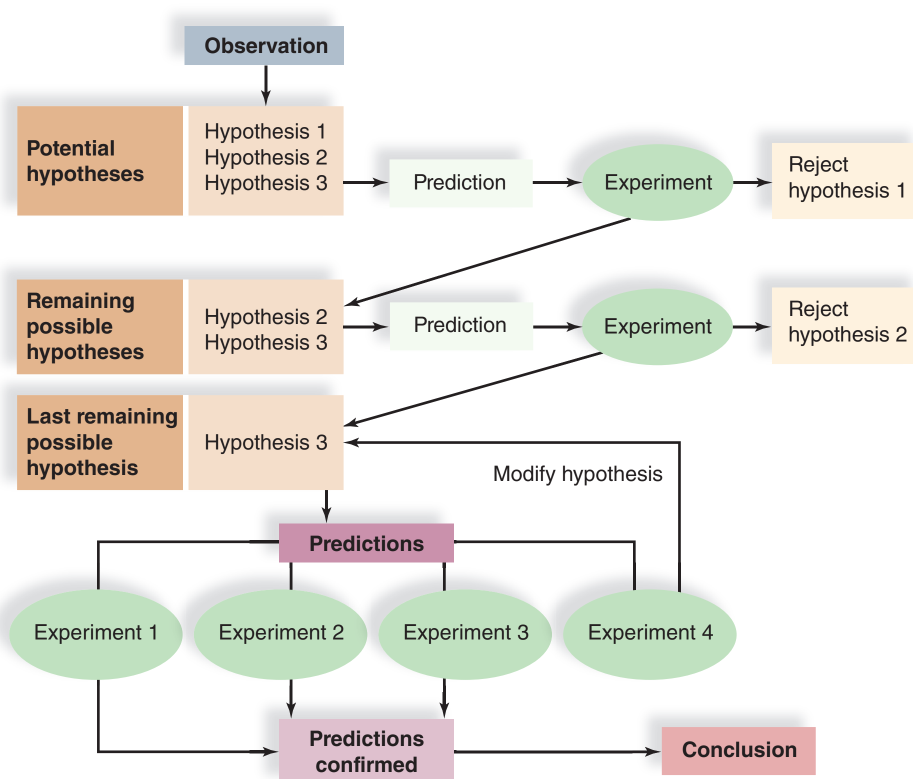


Figure 1.6 Flow diagram for the scientific method. On the basis of new and/or previous observations, a scientist formulates a hypothesis. The hypothesis is used to develop predictions to be tested by further experiments and/or observations, and new data either support or do not support the hypothesis. 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.