TWELFTH EDITION

BIOLOGY

Sylvia S. Mader
Michael Windelspecht

McGraw Hill Education

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With contributions by

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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 thirteenth edition. Highly acclaimed for her crisp and entertaining writing style, her books have become models for others who write in the field of biology.

Although her writing schedule is always quite demanding, 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 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.

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 currently serves as an adjunct professor of biology at ASU where he teaches nonmajors biology and human genetics in the online and hybrid formats. He was educated at Michigan State University and the University of South Florida. Dr. Windelspecht is also active in promoting the scientific literacy of secondary school educators. He has led multiple workshops on integrating water quality research into the science curriculum, and has spent several summers teaching Pakistani middle school teachers.

As an author, Dr. Windelspecht has published five reference textbooks, and multiple print and online lab manuals. He served as the series editor for a ten-volume work on the human body. For years Dr. Windelspecht has been active in the development of multimedia resources for the online and hybrid science classrooms. Along with his wife, Sandra, he owns a multimedia production company, Ricochet Creative Productions, which actively develops and assesses new technologies for the science classroom.

Contributors

Jason Carlson is a Biology Instructor at St. Cloud Technical and Community College in Minnesota where he teaches introductory biology, microbiology, nutrition, and human biology. Before entering higher education, he was a middle and high school science teacher with education from the University of Idaho, Bemidji State University, and St. Cloud State University. In the classroom, he supports a student-driven applied curriculum with relevant and hands-on research and investigation.

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

Gretel Guest is a Professor of Biology at Durham Technical Community College, in Durham, North Carolina. She has been teaching nonmajors and majors Biology, Microbiology, and Genetics for more than 15 years. Dr. Guest was educated in the field of botany at the University of Florida, and received her Ph.D. in Plant Sciences from the University of Georgia. She is also a Visiting Scholar at Duke University's Graduate School. There she serves the Preparing Future Faculty program by mentoring post-doctoral and graduate students interested in teaching careers. Dr. Guest was a contributor to the fourth edition of *Essentials of Biology*.

Jeffrey Isaacson is an Associate Professor of Biology at Nebraska Wesleyan University, where he teaches courses in microbiology, immunology, pathophysiology, infectious disease, and senior research. He also serves as the Assistant Provost for Integrative and Experiential Learning. Dr. Isaacson was educated at Nebraska Wesleyan, Kansas State College of Veterinary Medicine, and Iowa State University. He worked as a small-animal veterinarian in Nevada and California, and completed a post-doctoral fellowship in the Department of Immunology at the Mayo Clinic in Minnesota. Dr. Isaacson has been a significant contributor and coauthor for three editions of *Inquiry Into Life,* for the eleventh edition of *Biology,* and is a frequent contributor to McGraw-Hill's LearnSmart adaptive learning program for several textbooks.

Preface

Goals of the Twelfth Edition

The mission of Dr. Sylvia Mader's text, *Biology,* has always been to give students an understanding of biological concepts and a working knowledge of the scientific process. However, like the world around us, the process of teaching science is changing rapidly. Increasingly, instructors are being asked to engage their students by making content more relevant, while still providing students with a firm foundation in those core principles on which biology is founded. These changes are clearly outlined in the AAAS/NSF report, *Vision and Change in Undergraduate Biology Education* (2009). The eleventh edition of *Biology* was one of the first texts to address the principles of *Vision and Change* by integrating themes within the text. In this edition we expand on that effort with the development of a number of new resources and processes.

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 the *Biology* text, and its authors, are at the forefront of the integration of these technologies into the science classroom.

In this edition, the authors focused on the following areas:

1. utilization of the data from the LearnSmart adaptive learning platforms to identify content areas within the text that students demonstrated difficulty in mastering,
2. further development of the themes that connect the content of the text across multiple chapters,
3. development of a new series of videos and websites to introduce relevancy and engage students in the content,
4. refinement of digital assets to provide a more effective assessment of learning outcomes to enable instructors in the flipped, online, and hybrid teaching environments.

Relevancy

The use of real world examples to demonstrate the importance of biology in the lives of students is a key component of *Vision and Change* and an effective teaching strategy for introductory biology. The development of relevancy-based resources is a major focus for the authors of the Mader series of texts. Some examples 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 Sessions, 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 ix.

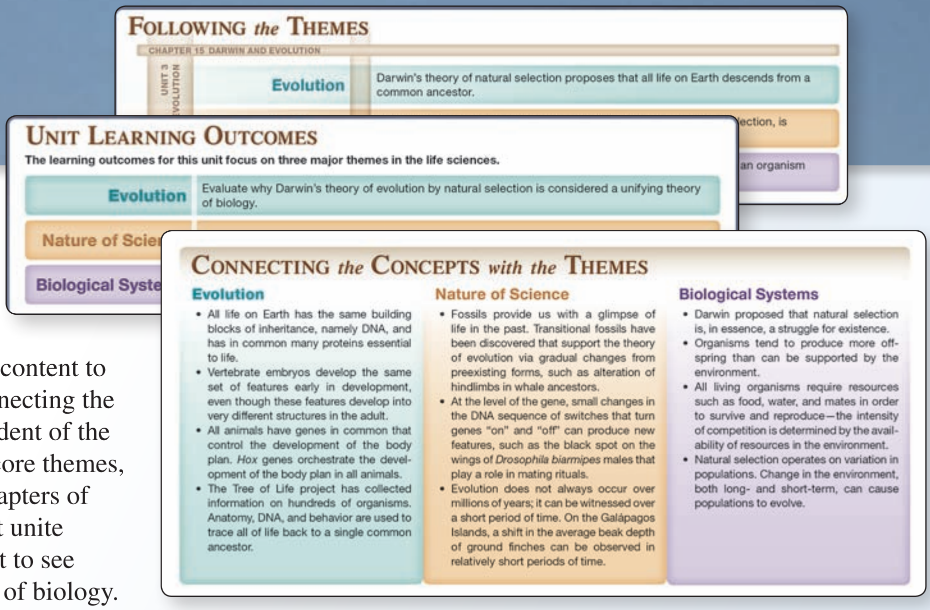
- A new website, RicochetScience.com that provides updates on news and stories that are interesting to nonscience majors. The Biology101 project links these resources to the major topics of the text. The site also features videos to assist the students in recognizing the relevancy of what they are learning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

Ricochet Science™

The Vision and Change document clearly identifies the need to integrate core concepts throughout the curriculum. We recognize that scientific literacy is not based upon the memorization of a series of facts. Instead, learning is based on establishing associations and links between what, at first glance, appear to be diverse topics. The main themes we have chosen to emphasize include:

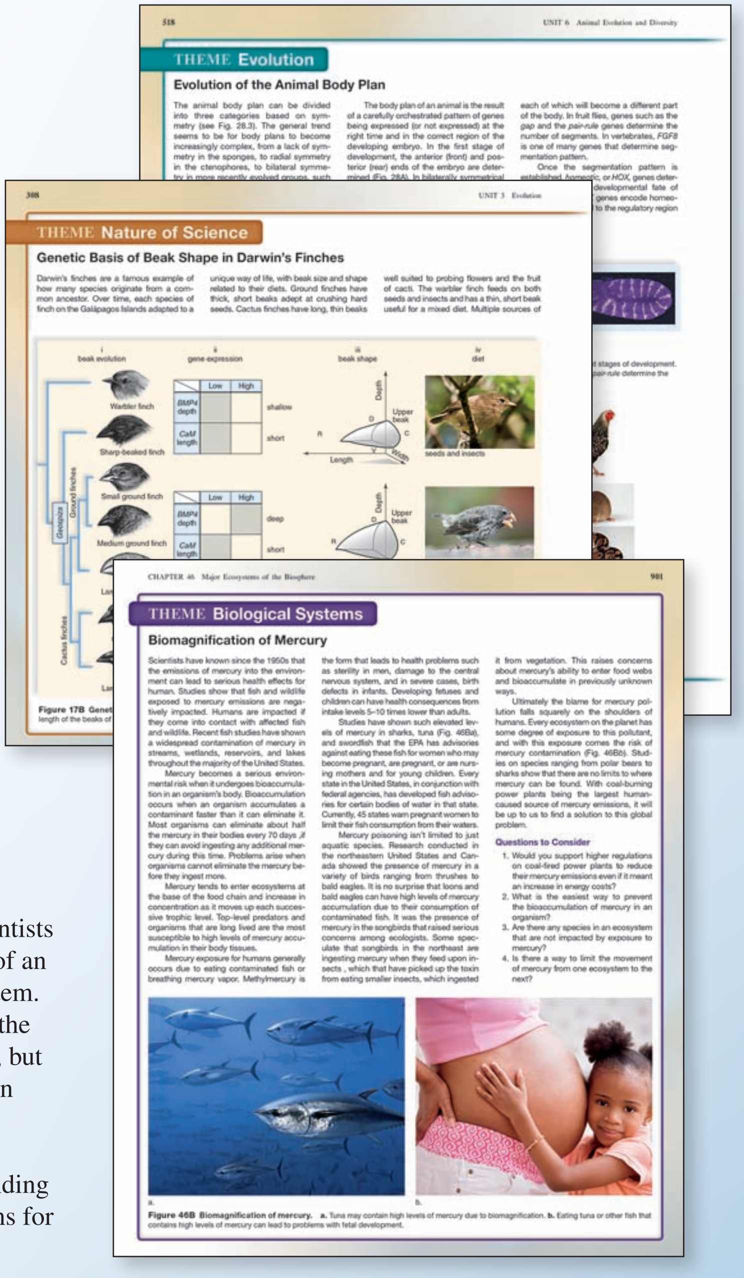
- Evolution
- Nature of Science
- Biological Systems

These themes are integrated into all aspects of the textbook, from the unit learning outcomes to the theme-based feature readings in the text. At the start of each chapter, "Following the Themes" introduces the relationship of the chapter's content to each of the themes. At the end of each chapter, "Connecting the Concepts with the Themes" not only reminds the student of the relationships between chapter content and the three core themes, but also acts as a prelude to topics in the next few chapters of the text. In essence, the themes act as the threads that unite the concepts throughout the text, enabling the student to see relationships from the molecular to ecosystem levels of biology.



Evolution Theme

Evolutionary change, along with the mechanism of natural selection, represents the unifying concept of the biological sciences. In essence, biological evolution is the thread that links all life together. Throughout this textbook, feature readings on this theme both demonstrate the process of evolution and illustrate how scientists study and measure evolutionary change. By following this theme through the book, students develop a better understanding of why evolution is a dynamic process, and one that has shaped, and will continue to influence, life on this planet.



Nature of Science Theme

Through the processes of observation, the application of the scientific method, and the use of both inductive and deductive reasoning, scientists study life. To develop a deeper understanding of the biological sciences, students must appreciate that the study of life is a process, and that this process has application in their everyday lives. This theme focuses not only on how biologists do science, but also on the influences scientific inquiry has on our understanding of our world.

Biological Systems Theme

From cells to ecosystems, all life is interconnected. Increasingly, scientists are becoming aware that small changes in the chemical composition of an ecosystem can have a tremendous influence on the life in that ecosystem. This theme was chosen to provide a holistic approach to the study of the life sciences, by demonstrating not only that all life is interconnected, but also that the principles regulating life at the cellular level play a role in physiology and ecosystem biology as well.

Assessment To help instructors assess their student's understanding of these core concepts, we have designed a series of Connect questions for each theme in each unit of the text .

Author's Guide to Using the Textbook

I encourage my students to use the **Before You Begin** feature to identify concepts they need to review before beginning to read the chapter content.

BEFORE YOU BEGIN

Before beginning this chapter, take a few moments to review the following discussions.

Figure 6.1 How does energy flow in biological systems?

Section 6.3 What role do enzymes play in regulating metabolic processes?

Section 6.4 How are redox reactions and membranes used to conduct cellular work?

I use **LearnSmart Labs** to encourage critical thinking, teach scientific processes, and to integrate lab activities into the classroom environment.

ENGAGE

LEARNSMART LABS®

The following LearnSmart Labs contain exercises that are related to the content of this chapter:

- Photosynthesis

Pre-Class

Built-in Preview and Review Tools

Students come to class prepared

During Class

Discussion Questions and Activities

Flip class and engage students

Learning Outcomes at the start of each section provide a preview of the content to come, while the **Check Your Progress** feature at the end of the section helps my students assess how well they understand the material. The learning outcomes are the same ones used in **Connect,** so I can easily assign a quiz to assess which topics I need to clarify during class.

7.2 The Process of Photosynthesis

Learning Outcomes

Upon completion of this section, you should be able to

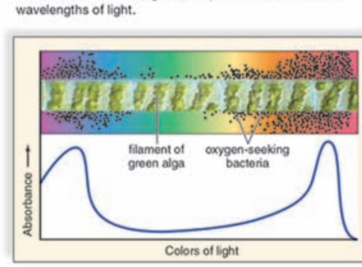
1. Describe the overall process of photosynthesis.
2. Compare energy input and output of the light reaction
3. Compare carb
   reaction.

Check Your Progress 7.2

1. Explain how redox reactions are used in photosynthesis.
2. Describe the role of enzymes during photosynthesis.

THINKING SCIENTIFICALLY

1. In the image below, the alga is the autotroph and undergoes photosynthesis, whereas the bacteria (small, black dots) are the heterotrophs. Explain why the bacteria are clustered at the far ends after the alga was exposed to different color wavelengths of light.



2. A Belgian doctor, Jan Baptista van Helmont (1580–1644) planted a small willow tree in a pot of soil. He weighed the tree and the soil. The tree was watered for 5 years and weighed 74.4 kg more than when he began, and the soil lost 57 g of mass. Explain what accounts for the plant's increase in biomass.

I use the **Questions to Consider** at the end of each reading and **Thinking Scientifically** questions at the end of the chapter as the basis for class discussions and active learning exercises.

MEDIA STUDY TOOLS http://connect.mheducation.com

SMARTBOOK® Study smart. SmartBook helps you maximize your study time by identifying what you know and don't know. The recharge feature in SmartBook helps you prepare for the test by identifying the material that you are most likely to forget.

connect | BIOLOGY Find even more resources to learn the chapter concepts including animations, tutorial videos, and interactive practice questions.

Animations	3D Animations	Tutorials
7.3 ATP Production in the Electron Transport Chain • Proton Pump	**7.1** Photosynthesis: Structure of a Chloroplast **7.3** Photosynthesis: Properties of Light • Photosynthesis: Light-Dependent Reactions **7.4** Photosynthesis: Calvin Cycle	**7.3** Noncyclic Photosynthesis **7.4** Calvin Cycle

Media Study Tools includes a table that shows students the animations, videos, and multimedia assets that are available to further explain difficult topics. These may be used as tutorials for the students, and I may assign the accompanying Connect activities to gauge whether my students understand the content.

Post-Class

Assessment and Integration

Apply content and build critical thinking

Traditional end-of-chapter summaries and review questions provide students with an opportunity for low-stakes assessment of their comprehension of the chapter's topics.

Features like **Following the Themes** and **Connecting the Concepts with the Themes** help them understand how the main concepts of the chapter relate to each other, building a deeper understanding of the content.

CONNECTING *the* CONCEPTS *with the* THEMES

Evolution

- Plants have evolved to capture solar energy and store it in carbon-based organic nutrients. These are passed on to organisms that have evolved to feed on plants, in turn to organisms that have evolved to feed on the plant-eaters, and so on in a food web.
- Plants are called autotrophs because they make their own organic food. Heterotrophs are organisms that take in organic food made by other organisms.

Nature of Science

- The amount of carbon dioxide in the atmosphere is increasing steadily, in part because of burning fossil fuels. This buildup of carbon dioxide causes global climate change, and we can use the tools of science to understand the scope of this change.
- Scientists are learning how to manipulate photosynthesis to create commercially important products such as oils and turpentines.

Biological Systems

- Autotrophs take in carbon dioxide when they photosynthesize. Carbon dioxide is returned to the atmosphere when autotrophs and heterotrophs carry on cellular respiration. In this way, carbon atoms cycle through living organisms.
- Energy does not cycle; therefore, all life is dependent on the ability of plants to capture solar energy and produce carbohydrate molecules from CO_2.

Author's Guide to the Digital Classroom

- module: Chapter 8. Cellular Reproduction

Frequency	Question
30	How many chromosomes would a human liver cell have after undergoing mitosis? (Try probe)
26	The process by which a cancer travels through the blood and lymphatic vessels and then invades new tissues is called ________. (Try probe)
26	________ is the mitotic phase during which daughter chromosomes are present at opposite poles and nuclear envelopes reform. (Try probe)
22	In early development human fingers are webbed, but are later freed as ______ destroys some of the cells. (Try probe)
20	Define spindle. (Try probe)
20	Using the diagram list, in order, the steps from a living cell to apoptosis. (Try probe)
19	During periods of cell division, DNA and its associated proteins are wrapped and packaged into a short, bar-like structure called a ______. (Try probe)
15	Define signal factor. (Try probe)
15	In animal cells the actual division of the cytoplasm, cytokinesis, occurs as a cleavage furrow forms. What kind of proteins operate to form this furrow? (Try probe)
15	Humans have a total of ______ chromosomes in each cell in their body. (Try probe)

Using reports from within the LearnSmart system, especially the Most Missed Questions report, I am able to identify areas of content that my students are struggling with before they enter the lecture.

Pre-Class

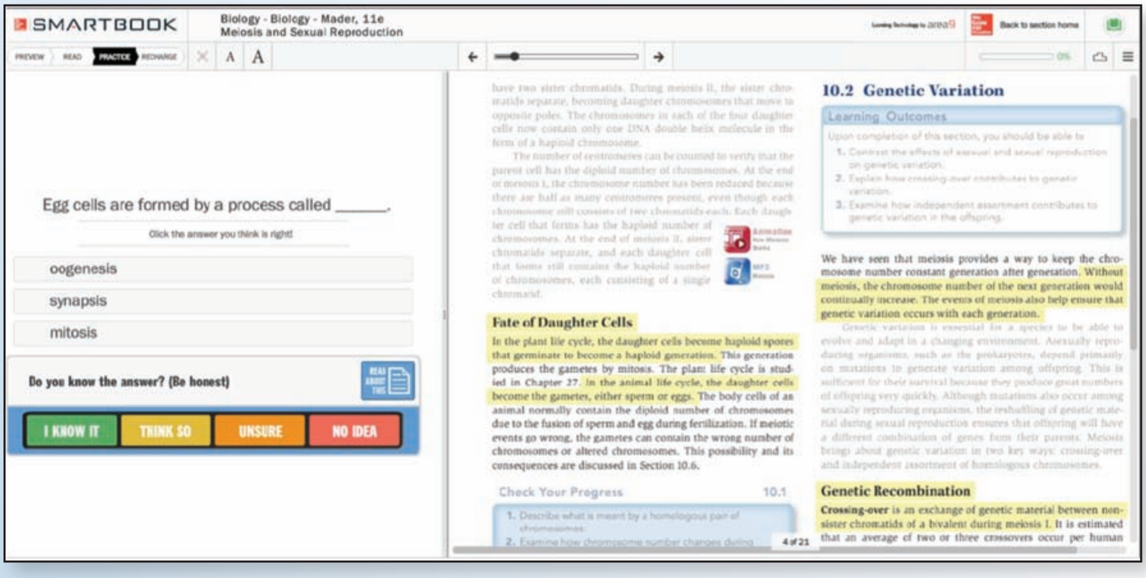
LearnSmart & SmartBook

Students come to class prepared

During Class

Instructor Resources

Flip class and engage students



I generally assign 20-30 minutes of SmartBook 3-5 days before class. The assignments cover only the core topics for the upcoming lesson.

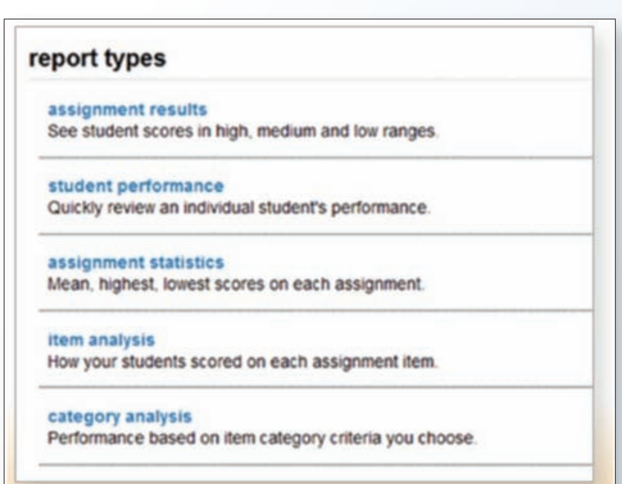
During class I can focus on engaging the students with the relevancy of the content using the BioNow Sessions videos, active learning exercises, and animations. Tegrity lecture capture lets my students review these concepts later.

Post-Class

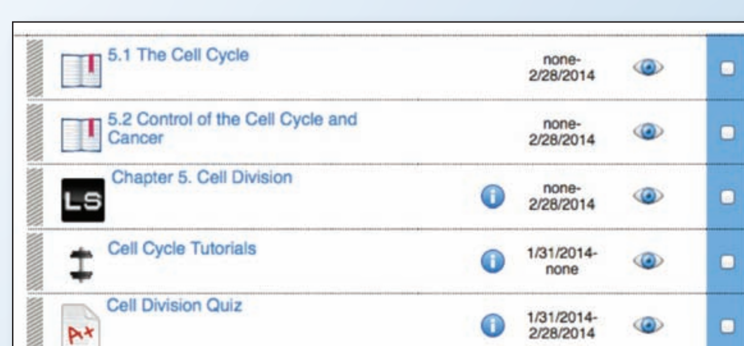
Connect

Apply content and build critical thinking

Using feedback from the LearnSmart reports, I am able to design Connect assignments that act as tutorials that target the concepts my students are struggling with.



The Connect reports allow me to assess whether my students have met the learning objectives.



The quizzing option within Connect allows me to develop assessments for any classroom environment.

Engaging Your Students

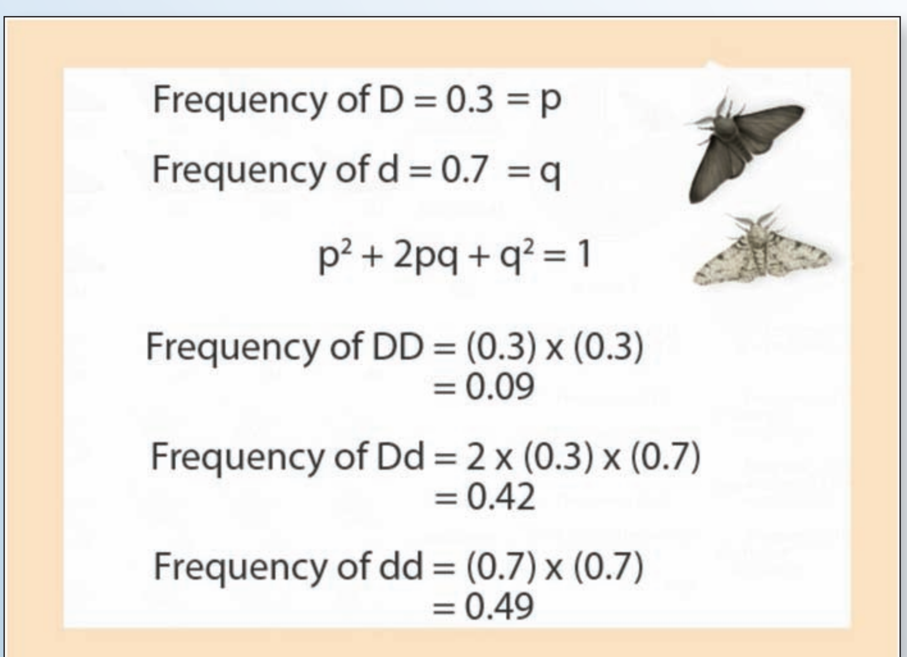
Today's science classroom relies heavily on the use of digital assets, including animations and videos, to engage students and reinforce difficult concepts. Biology 12e includes two resources specifically designed for the introductory science class to help you achieve these goals.

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 27-video series narrated and produced by author Jason Carlson



A 36-animation series narrated by Michael Windelspecht and produced by Ricochet Creative Productions, LLC

Our new tutorials 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

THEME Evolution

THEME Biological Systems

THEME Nature of Science

Overview of Content Changes to *Biology,* Twelfth Edition

Chapter 1: A View 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: The Cell

Chapter 2: Basic Chemistry starts with new content on the search for life on Mars. **Chapter 3: The Chemistry of Organic Molecules** opens with a look at trans fats in common foods. **Chapter 5: Membrane Structure and Function** begins with a new opening article on chili peppers and calcium channels. **Chapter 6: Metabolism: Energy and Enzymes** includes new material on the function of ATP in cells. The content on redox reactions now focuses more on the processes of photosynthesis and cellular respiration. **Chapter 7: Photosynthesis** begins with new content on biofuels.

Unit 2: Genetic Basis of Life

Chapter 9: The Cell Cycle and Cellular Reproduction now contains information on the structure of a eukaryotic chromosome (section 9.2). **Chapter 10: Meiosis and Sexual Reproduction** starts with a new essay on the importance of meiosis and a new featured reading, "Meiosis and the Parthenogenic Lizards." The figure comparing meiosis I and II (Fig. 10.5) has been reworked to provide an easier comparison of the two processes. **Chapter 11: Mendelian Patterns of Inheritance** begins with a new essay on PKU sensitivity. A new featured reading examines hemophilia and the royal families of Europe. The content on polygenic inheritance now contains references to the genetics of skin coloring (Fig. 11.17). **Chapter 12: Molecular Biology of the Gene** has a new chapter opener that explains the genetic basis of skin, hair, and eye coloration. The content on the eukaryotic chromosome has been moved to chapter 9. There is a new illustration on semiconservative replication (Fig 12.6) and a new featured reading that examines GFP protein. **Chapter 13: Regulation of Gene Expression** starts with new content on how gene regulation relates to the physiology and behavior of primates. A new featured reading, "Same but Not the Same—the Role of Epigenetics," has been included on epigenetic inheritance. **Chapter 14: Biotechnology and Genomics** opens with a new essay on how biotechnology is being used to treat dental disease. New illustrations on the PCR reaction (Fig. 14.3) and the nature of transposons (Fig. 14.10) are included.

Unit 3: Evolution

Chapter 16: How Populations Evolve opens with an essay on MRSA evolution. **Chapter 17: Speciation and Macroevolution** contains an updated illustration on allopatric speciation (Fig. 17.8).

Unit 4: Microbiology and Evolution

Chapter 20: Viruses, Bacteria, and Archaea contains a new featured reading, "DIY Bio," that examines synthetic biology. A new illustration (Fig. 20.8) on gram staining is included. **Chapter 21: Protist Evolution and Diversity** has been restructured to give more emphasis on the supergroup classification system. The chapter begins with a new opener on *Naegleria fowleri,* and contains a new featured reading on pathogenic protists and climate change. The evolutionary relationships in **Chapter 22: Fungi Evolution and Diversity** now includes the microsporidia (Fig. 22.1).

Unit 5: Plant Evolution and Biology

Chapter 23: Plant Evolution and Diversity contains a new featured reading, "Bryophytes—Frozen in Time." **Chapter 24: Flowering Plants: Structure and Organization** begins with new content on the importance of the neem tree. The chapter has been reorganized to start with content on plant cells and tissues before exploring organ systems. **Chapter 25: Flowering Plants: Nutrition and Transport** now contains information on hydroponics (Fig. 25.2) and effects of nutrient deficiencies on plants (Fig. 25.3). Table 26.1 in **Chapter 26: Flowering Plants: Control of Growth Responses** now contains the chemical structures of the plant hormones. A new featured reading explores coevolution and the chemical ecology of plants. **Chapter 27: Flowering Plants: Reproduction** begins with a new essay on the economic importance of flowers.

Unit 6: Animal Evolution and Diversity

Chapter 28: Invertebrate Evolution begins with new content that examines the importance of colony-collapse disorder in honeybees. A new featured reading, "Would You Eat Insects?," discusses the potential benefits of using insects as a food source. **Chapter 30: Human Evolution** contains a new featured reading that explores some of the remaining questions on human evolution.

Unit 7: Comparative Animal Biology

Chapter 31: Animal Organization and Homeostasis begins with an essay that examines the importance of homeostasis for astronauts. **Chapter 32: Circulation and Cardiovascular Systems** opens with material on cardiovascular-related diseases and the NFL. **Chapter 33: The Lymphatic and Immune Systems** has a new opener on foods and anaphylactic shock. **Chapter 34: Digestive Systems and Nutrition** contains a new featured reading on gluten-free diets. **Chapter 35: Respiratory Systems** has a new figure (Fig. 35.8) explaining the relationship between air pressure and volume of a container. The chapter also contains a new featured reading on the health aspects of using e-cigarettes. **Chapter 37: Neurons and Nervous Systems** begins with new content on Parkinson disease. **Chapter 39: Locomotion and Support Systems** starts with a new essay on Olympian Gabby Douglas. **Chapter 41: Reproductive Systems** has a new opener that explores variations between the sexes in the animal kingdom.

Unit 8: Behavior and Ecology

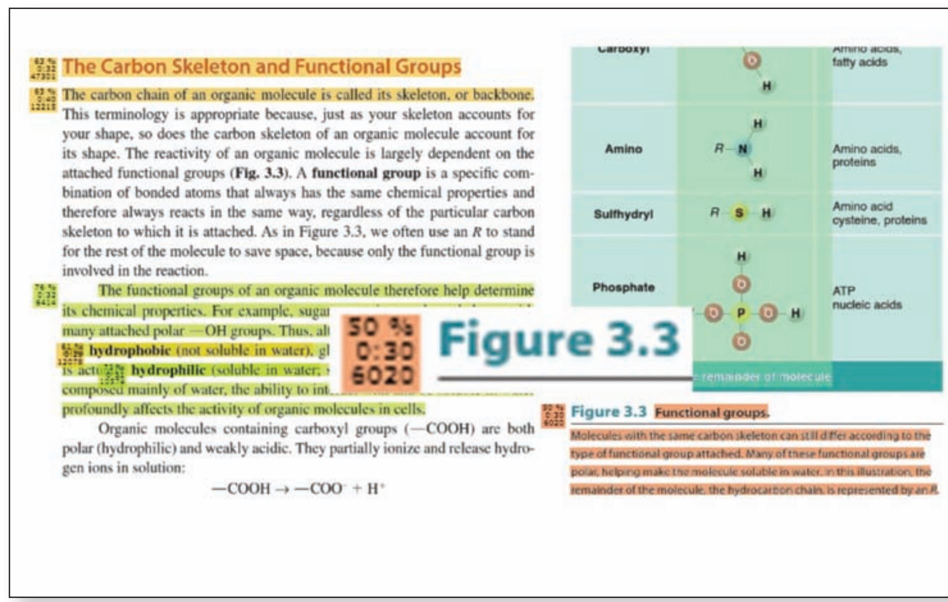
Chapter 43: Behavioral Ecology starts with content on behavior and communication in honeybees. The featured reading on animals and emotions has been updated to include recent developments. **Chapter 44: Population Ecology** contains a new illustration on the environmental impact of developed countries. The predator-prey relationships and content on global climate change in **Chapter 45: Community and Ecosystem Ecology** has been updated to include more recent data. **Chapter 47: Conservation of Biodiversity** now begins with an essay on the impact of invasive species.

The Next Generation of Textbook Reviews: Heat Map Technology

The twelfth edition of *Biology* is the first textbook in the Mader series which utilized the data derived from the LearnSmart platform as a form of review,

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 represents 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 the phenomenal team of science educators and coauthors on this edition. They are all dedicated and talented teachers, and their passion is evident in the quality of this text. Thank you also to the countless instructors who have invited me into their classrooms, both physically and virtually, to discuss their needs as instructors and the needs of their students. Your energy, and devotion to quality teaching, is what drives a textbook revision.

Many dedicated and talented individuals assisted in the development of this edition of *Biology.* I am very grateful for the help of so many professionals at McGraw-Hill who were involved in the development of this project. In particular, let me thank my product developer, Anne Winch, for not only keeping me on track and her valuable advice, but for her endless patience. My editor for this text was Chris Loewenberg. From start to finish a project of this magnitude can take over 18 months, and Chris has the natural ability of keeping his authors focused and in reminding me of the importance we are making in education. Thanks also to my marketing manager, Chris Ho, who offers a unique insight on the needs of our students. No modern team would be complete without digital support, and for that I thank Eric Weber and Christine Carlson.

Production of this text was directed by Angela Fitzpatrick and Jayne Klein, who faithfully steered this project through the publication process. I was very lucky to have Dawnelle Krouse, Deb Debord, and Rose Kramer as proofreaders and copy editors. Today's textbooks are visual productions, and so I need to thank the creative talents of David Hash. Lori Hancock and Evelyn Jo Johnson did a superb job of finding just the right photographs and micrographs. Electronic Publishing Services produced this textbook, emphasizing pedagogy and beauty to arrive at the best presentation on the page.

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 support of my projects. 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
Blowing Rock, NC

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Appendices

The themes of evolution, the nature of science, and biological systems are important to understanding biology.

1

A View of Life

Chapter Outline

Our planet is home to a staggering diversity of life. It is estimated that there are over 15 million different species, including our species, *Homo sapiens,* that inhabit the globe. Furthermore, life may be found everywhere, from the deepest trenches in the oceans to the tops of the highest mountains. Biology is the area of scientific study that focuses on understanding all aspects of living organisms. To further our understanding of what it means to be alive, biologists explore life from the molecular level of the information in our genes to the large-scale ecological interactions of multiple species and their environments.

In this text, we are going to focus on three themes that define these explorations. The first is evolution—the central theme of biology and the explanation for how life adapts and changes over time. The second theme is the nature of science. Science is a process that relies on experimentation and hypothesis testing to validate its findings. The third theme is biological systems. Throughout this text you will discover that life is interconnected at many levels, from similarities in our genetic information to the cycling of nutrients in ecosystems.

As we proceed through this chapter, consider how we as humans are interconnected with other species by these three themes.

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

1. Why is evolution a central theme of the biological sciences?
2. In what ways is life interconnected?
3. How do scientists use the scientific method to study life?

Following *the* Themes

CHAPTER 1 A VIEW OF LIFE

Evolution	**Understanding the scientific process, the theory of evolution, and the interaction of biological systems is important in the study of biology.**
Nature of Science	**Scientists make observations, form hypotheses, and conduct experiments in an attempt to understand the principles of life.**
Biological Systems	**From communities of organisms to individual cells, all life is based on atoms and molecules.**

1.1 The Characteristics of Life

Learning Outcomes

Upon completion of this section, you should be able to

1. Distinguish among the levels of biological organization.
2. Identify the basic characteristics of life.

Biology is the scientific study of life. Life on Earth takes on a staggering variety of forms, often functioning and behaving in ways strange to humans. For example, gastric-brooding frogs swallow their embryos and give birth to them later by throwing them up! Some species of puffballs, a type of fungus, are capable of producing trillions of spores when they reproduce. Fetal sand sharks kill and eat their siblings while still inside their mother. Some *Ophrys* orchids look so much like female bees that male bees try to mate with them. Octopuses and squid have remarkable problem-solving abilities despite a small brain. Some bacteria live their entire life in 15 minutes, while bristlecone pine trees outlive 10 generations of humans. Simply put, from the deepest oceanic trenches to the upper reaches of the atmosphere, life is plentiful and diverse.

Figure 1.1 illustrates the major groups of living organisms. From left to right, bacteria are widely distributed, microscopic organisms with a very simple structure. A *Paramecium* is an example of a microscopic protist. Protists are larger in size and more complex than bacteria. The other organisms in Figure 1.1 are easily seen with the naked eye. They can be distinguished by how they get their food. A morel is a fungus that digests its food externally. A sunflower is a photosynthetic plant that makes its own food, and an octopus is an aquatic animal that ingests its food.

Although life is tremendously diverse, it may be defined by several basic characteristics that are shared by all organisms. Like nonliving things, organisms are composed of chemical elements. Also, organisms obey the same laws of chemistry and physics that govern everything within the universe. The characteristics of life, however, provide insight into the unique nature of life, and help to distinguish living organisms from nonliving things.

Life Is Organized

The complex organization of life (Fig. 1.2) begins with **atoms,** the basic units of matter. Atoms combine to form small **molecules,** which join to form larger molecules within a **cell,** the smallest, most basic unit of life. Although a cell is alive, it is made from nonliving molecules. Some cells, such as single-celled *Paramecium,* live independently. In some cases, single-celled organisms clump together to form colonies, as does the alga *Volvox*.

Many living organisms are **multicellular,** meaning they contain more than one cell. In multicellular organisms, similar cells combine to form a **tissue—**for example, the nerve and muscle tissues of animals. Tissues make up **organs,** such as the brain or a leaf. Organs work together to form **organ systems;** for example, the brain works with the spinal cord and a network of nerves to form the nervous system. Organ systems are joined together to form an **organism,** such as an elephant.

The levels of biological organization extend beyond the individual organism. All the members of one species (a group of similar, interbreeding organisms) in a particular area belong to a **population.** A nearby forest may have a population of gray squirrels and a population of white oaks, for example. The populations of various animals and plants in the forest make up a **community.** The community of populations interacts with the physical environment (water, land, climate) to form an **ecosystem.** Collectively, all the Earth's ecosystems make up the **biosphere.**

You should recognize from Figure 1.2 that each level of biological organization builds upon the previous level and is more complex. Moving up the hierarchy, each level acquires new *emergent properties,* or new, unique characteristics, that are determined by the interactions between the individual parts. For example, when cells are broken down into bits of membrane and liquids, these parts themselves cannot carry out all the basic characteristics of life. However, all the levels of biological organization are interconnected and function as biological systems. For example, a change in carbon dioxide concentrations (a small molecule) may negatively influence the operation of organs, organisms, and entire ecosystems. In other words, life is interconnected at a variety of levels.

Bacteria | *Paramecium* | Morel | Sunflower | Octopus

Figure 1.1 Diversity of life. Biology is the scientific study of life. This is a sample of the many diverse forms of life that are found on planet Earth.

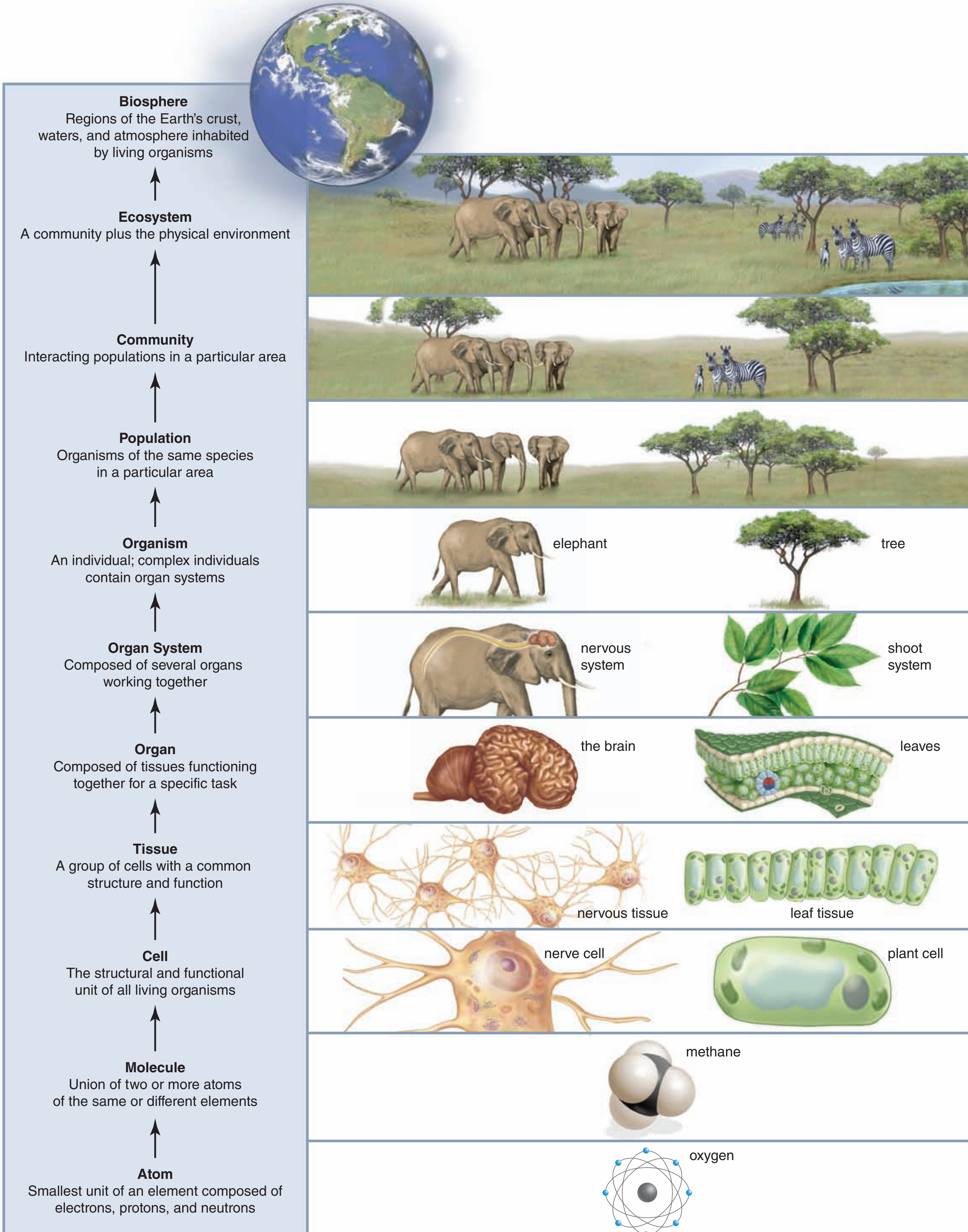


Figure 1.2 Levels of biological organization. The basic functional unit of life is the cell, which is built from nonliving molecules and atoms.

Life Requires Materials and Energy

Living organisms cannot maintain their organization or carry on life's activities without an outside source of nutrients and energy (Fig. 1.3). Food provides nutrients, which are used as building blocks or for energy. **Energy** is the capacity to do work, and it takes work to maintain the organization of the cell and the organism. When cells use nutrient molecules to make their parts and products, they carry out a sequence of chemical reactions. The term **metabolism** (Gk. *meta,* "change") encompasses all the chemical reactions that occur in a cell.

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. 1.4). 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. 1.4) 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.

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.

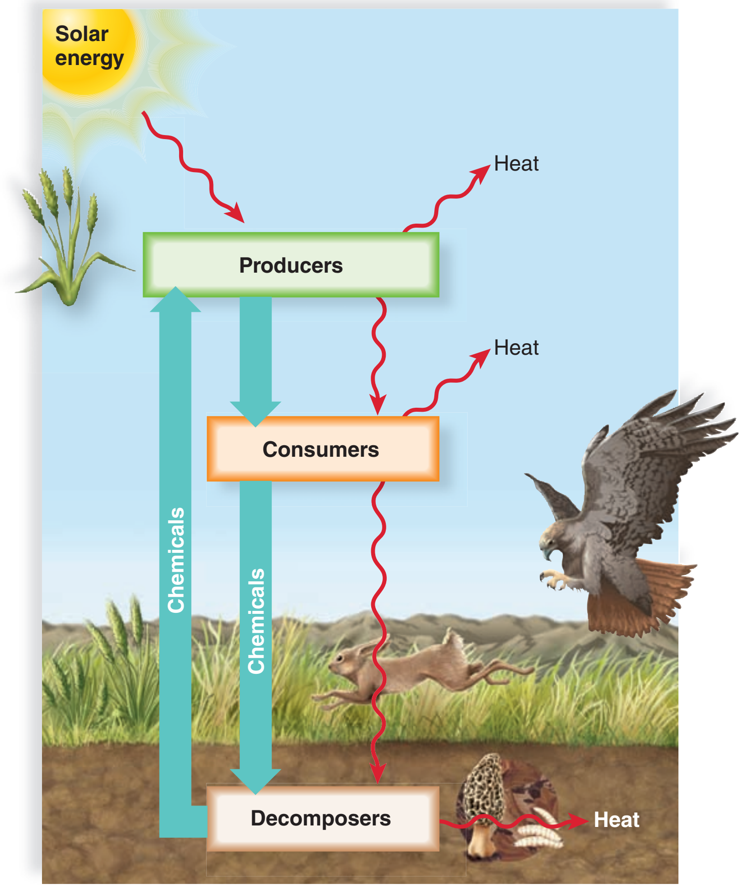


Figure 1.4 Chemical cycling and energy flow in an ecosystem. In an ecosystem, chemical cycling (aqua arrows) and energy flow (red arrows) begin when plants use solar energy and inorganic nutrients to produce their own food. Chemicals and energy are passed from one population to another in a food chain. Eventually, energy dissipates as heat. With the death and decomposition of organisms, chemicals are returned to living plants once more.

Figure 1.3 Acquiring nutrients and energy. All life, including this bear and the fish, need to acquire energy.

Living Organisms Maintain Homeostasis

To survive, it is imperative that an organism maintain a state of biological balance, or **homeostasis** (Gk. *homoios,* "like"; *stasis*, "the same"). For life to continue, temperature, moisture level, acidity, and other physiological factors must remain within the tolerance range of the organism. Homeostasis is maintained by systems that monitor internal conditions and make routine and necessary adjustments.

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.

Living Organisms Respond

Living organisms interact with the environment as well as with other organisms. Even single-celled organisms can respond to their environment. In some, the beating of microscopic hairs or, in others, the snapping of whiplike tails moves them toward or away from light or chemicals. Multicellular organisms can manage more complex responses. A vulture can detect a carcass a kilometer away and soar toward dinner. A monarch butterfly can sense the approach of fall and begin its flight south, where resources are still abundant.

The ability to respond often results in movement: The leaves of a land plant turn toward the sun, and animals dart toward safety. Appropriate responses help ensure the survival of the organism and allow it to carry on its daily activities. All together, these activities are termed the *behavior* of the organism. Organisms display a variety of behaviors as they maintain homeostasis and search and compete for energy, nutrients, shelter, and mates. Many organisms display complex communication, hunting, and defense behaviors.

Living Organisms Reproduce and Develop

Life comes only from life. All forms of life have the ability to **reproduce,** or 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, followed by many cell divisions, results in an immature stage, which proceeds through stages of **development,** or change, to become an adult.

When living organisms reproduce, their **genes,** or genetic instructions, are passed on to the next generation. Random combinations of sperm and egg, each of which contains a unique collection of genes, ensure that the offspring has new and different characteristics. An embryo develops into a whale, a yellow daffodil, or a human because of the specific set of genes it inherits from its parents. In 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 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.

Mutations help create a staggering diversity of life, even within a group of otherwise identical organisms. Sometimes, organisms inherit characteristics that allow them to be more suited to their way of life.

Living Organisms Have Adaptations

Adaptations are modifications that make organisms better able to function in a particular environment. For example, penguins are adapted to an aquatic existence in the Antarctic. An extra layer of downy feathers is covered by short, thick feathers, which form a waterproof coat. Layers of blubber also keep the birds warm in cold water. Most birds have forelimbs proportioned for flying, but penguins have stubby, flattened wings suitable for swimming. Their feet and tails serve as rudders in the water, but the flat feet also allow them to walk on land. Penguins also have many behavioral adaptations to living in the Antarctic. Penguins often slide on their bellies across the snow in order to conserve energy when moving quickly (Fig. 1.5). They carry their eggs—one or at most two—on their feet, where the eggs are protected by a pouch of skin. This also allows the birds to huddle together for warmth while standing erect and incubating the eggs.

From penguins to giant sequoia trees, life on Earth is very diverse, because over long periods of time, organisms respond to ever-changing environments by developing new adaptations.

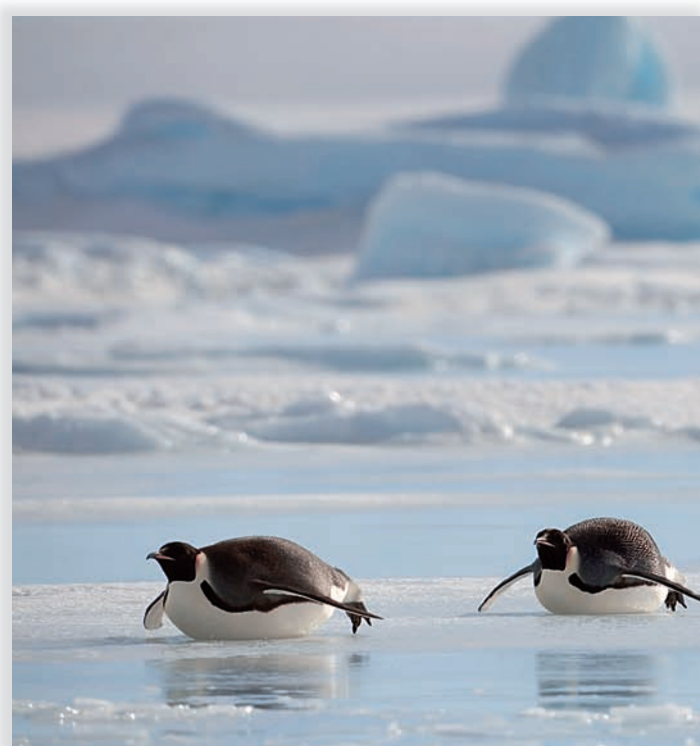


Figure 1.5 Living organisms have adaptations. Penguins have evolved complex behaviors, such as sliding across ice to conserve energy, to adapt to their environment.

These adaptations are unintentional, but they provide the framework for evolutionary change. **Evolution** (L. *evolutio,* "an unrolling") includes the way in which populations of organisms change over the course of many generations to become more suited to their environments. All living organisms have the capacity to evolve, and the process of evolution constantly reshapes every species on the planet, potentially providing a way for organisms to persist, despite a changing environment. We will take a closer look at this process in the next section.

MP3 Life Characteristics

Check Your Progress 1.1

1. Distinguish between an ecosystem and a population in the levels of biological organization.
2. List the common characteristics of all living organisms.
3. Explain how adaptations relate to evolutionary change.

1.2 Evolution and the Classification of Life

Learning Outcomes

Upon completion of this section, you should be able to

1. Explain the relationship between the process of natural selection and evolutionary change.
2. Distinguish among the three domains of life.

Despite diversity in form, function, and lifestyle, organisms share the same basic characteristics. As mentioned, they are all composed of cells organized in a similar manner. Their genes are composed of DNA, and they carry out the same metabolic reactions to acquire energy and maintain their organization. The unity of life suggests that they are descended from a common ancestor—the first cell or cells.

Evolution—the Core Concept of Biology

The phrase "common descent with modification" sums up the process of evolution, because it means that as descent occurs from common ancestors, so do modifications that cause organisms to be adapted to their environment. Through many observations and experiments, Charles Darwin came to the conclusion that **natural selection** is the process that makes modification—that is, adaptation—possible.

Natural Selection

During the process of natural selection, some aspect of the environment selects which traits are more apt to be passed on to the next generation. The selective agent can be an abiotic agent (part of the physical environment, such as altitude), or it can be a biotic agent (part of the living environment, such as a deer). Figure 1.6 shows how the dietary habits of deer might eventually affect the characteristics of the leaves of a particular land plant.

Mutations fuel natural selection, because mutation introduces variations among the members of a population. In Figure 1.6, a plant species generally produces smooth leaves, but a mutation occurs that causes one plant to have leaves that are covered with small extensions, or "hairs." The plant with hairy leaves has an advantage, because the deer (the selective agent) prefer to eat smooth leaves, not hairy leaves. Therefore, the plant with hairy leaves survives best and produces more seeds than most of its neighbors. As a result, generations later most plants of this species produce hairy leaves.

As with this example, Darwin realized that although all individuals within a population have the potential to reproduce, not all do so with the same success. Prevention of reproduction can be the result of a number of factors, including an inability to capture resources, as when long-necked but not short-necked giraffes can reach their food source, or an inability to escape being eaten because long legs, but not short legs, can carry an animal to safety.

Whatever the example, it can be seen that organisms with advantageous traits can produce more offspring than those that lack them. In this way, living organisms change over time, and these changes are passed on from one generation to the next. Over long periods of time, the introduction of newer, more advantageous traits into a population may drastically reshape a species. Natural

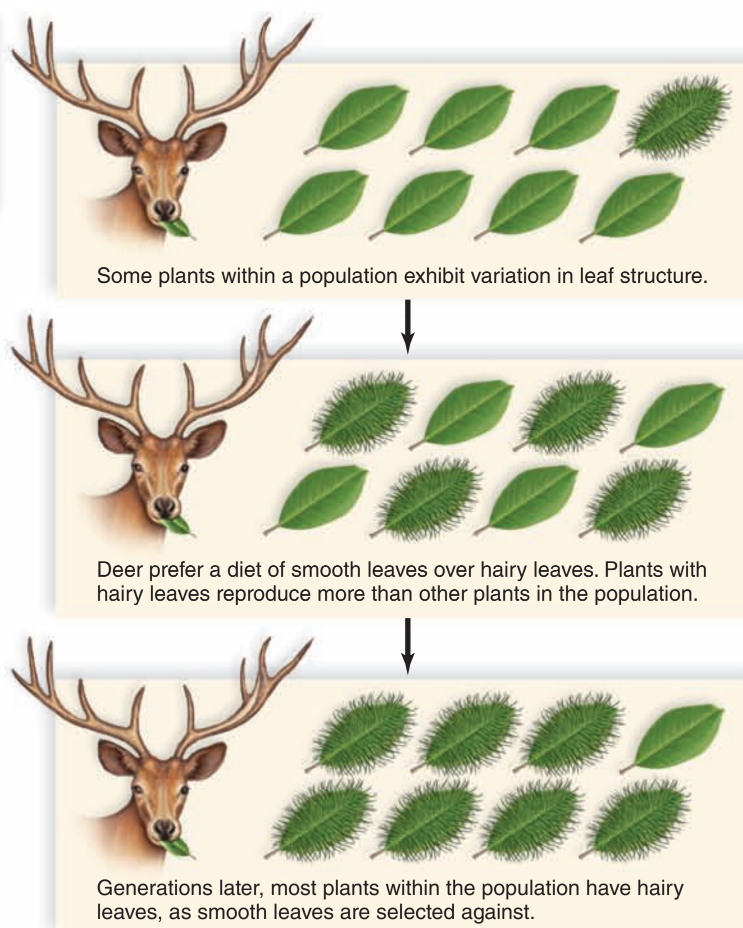


Figure 1.6 Natural selection. Natural selection selects for or against new traits introduced into a population by mutations. Over many generations, selective forces such as competition, predation, and the physical environment alter the makeup of a population, favoring those more suited to the environment and lifestyle.

selection tends to sculpt a species to fit its environment and lifestyle and can create new species from existing ones. The end result is the diversity of life classified into the three domains of life (Fig. 1.7).

Organizing Diversity

An evolutionary tree is like a family tree. Just as a family tree shows how a group of people have descended from one couple, an evolutionary tree traces the ancestry of life on Earth to a common ancestor (Fig. 1.7). One couple can have diverse children, and likewise a population can be a common ancestor to several other groups, each adapted to a particular set of environmental conditions. In this way, over time, diverse life-forms have arisen. Evolution may be considered the unifying concept of biology, because it explains so many aspects of it, including how living organisms arose from a single ancestor.

Because life is so diverse, it is helpful to group organisms into categories. **Taxonomy** (Gk. *tasso,* "arrange"; *nomos,* "usage") 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, or *taxa,* going from least inclusive to most inclusive, are **species, genus, family, order, class, phylum, kingdom,** and **domain** (Table 1.1). The least inclusive category, species (L. *species,* "model, kind"), is defined as a group of interbreeding individuals. Each successive classification category above species contains more types of organisms than the preceding one. Species placed within one genus share many specific characteristics and are the most closely related, while species placed in the same kingdom share only general characteristics with one another. For example, all species in the genus *Pisum* look pretty much the same—that is, like pea plants—but species in the plant kingdom can be quite varied, as is evident when we compare grasses to trees. Species placed in different domains are the most distantly related.

Table 1.1 Levels of Classification

Category	Human	Corn
Domain	Eukarya	Eukarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Anthophyta
Class	Mammalia	Monocotyledones
Order	Primates	Commelinales
Family	Hominidae	Poaceae
Genus	*Homo*	*Zea*
Species*	*H. sapiens*	*Z. mays*

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

Domains

Current biochemical evidence suggests that there are three domains: **domain Bacteria, domain Archaea,** and **domain Eukarya.** Figure 1.7 shows how the domains are believed to be related. Both domain Bacteria and domain Archaea may have evolved from the first common ancestor soon after life began. These two domains contain the **prokaryotes,** which lack the membrane-bound nucleus found in

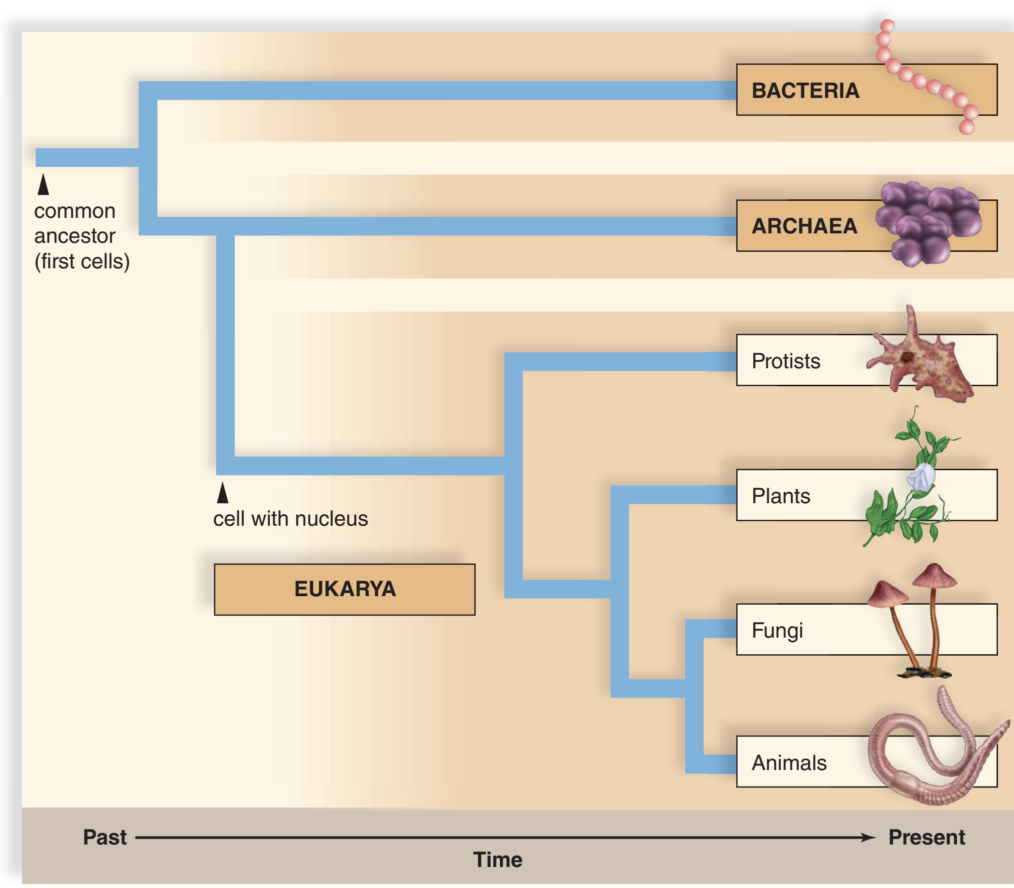


Figure 1.7 Evolutionary tree of life. As existing organisms change over time, they give rise to new species. Evolutionary studies show that all living organisms arose from a common ancestor about 4 billion years ago. Domain Archaea and domain Bacteria include the prokaryotes. Domain Eukarya includes both single-celled and multicellular organisms that possess a membrane-bound nucleus.

the **eukaryotes** of domain Eukarya. However, archaea organize their DNA differently than bacteria, and their cell walls and membranes are chemically more similar to eukaryotes than to bacteria. So, the conclusion is that eukarya split off from the archaeal line of descent.

Animation Three Domains

Prokaryotes are structurally simple but metabolically complex. Archaea (Fig. 1.8) can live in aquatic environments that lack oxygen or are too salty, too hot, or too acidic for most other organisms. Perhaps these environments are similar to those of the primitive Earth, and archaea (Gk. *archae,* "ancient") are the least evolved forms of life, as their name implies. Bacteria (Fig. 1.9) are variously adapted to living almost anywhere—in the water, soil, and atmosphere, as well as on our skin and in our mouth and large intestine.

Taxonomists are in the process of deciding how to categorize archaea and bacteria into kingdoms. Domain Eukarya, on the other hand, contains four major groups of organisms (Fig. 1.10). **Protists,** which comprise a number of kingdoms, range from single-celled forms to a few multicellular ones. Some are photosynthesizers, and some must acquire their food. Common protists include algae, the protozoans, and the water molds. Figure 1.7 shows that plants, fungi, and animals most likely evolved from protists. **Plants** (kingdom Plantae) are multicellular photosynthetic organisms. Example plants include azaleas, zinnias, and pines. Among the **fungi** (kingdom Fungi) are the familiar molds and mushrooms that, along with bacteria, help decompose dead organisms. **Animals** (kingdom Animalia) are multicellular organisms that must ingest and process their food. Aardvarks, jellyfish, and zebras are representative animals.

Scientific Name

Biologists use **binomial nomenclature** to assign each living organism a two-part name called a scientific name. For example, the scientific name for mistletoe is *Phoradendron tomentosum*. The first word is the genus, and the second word is the species designation (*specific epithet*) of each species within a genus. The genus may be abbreviated (e.g., *P. tomentosum*) and, if the species

Domain Archaea

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

Sulfolobus, an archaean

Figure 1.8 Domain Archaea.

Domain Bacteria

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

Escherichia coli, a bacterium

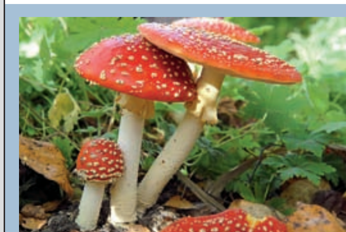
Figure 1.9 Domain Bacteria.

Domain Eukarya: Protists

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

Paramecium, a single-celled protozoan

Domain Eukarya: Kingdom Fungi



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

Amanita, a mushroom

Domain Eukarya: Kingdom Plantae

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

Phalaenopsis, orchid, a flowering plant

Domain Eukarya: Kingdom Animalia

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

Vulpes, a red fox

Figure 1.10 Domain Eukarya.

has not been determined, it may simply be indicated with a generic abbreviation (e.g., *Phoradendron* sp.). Scientific names are universally used by biologists to avoid confusion. Common names tend to overlap and often differ depending on locality and the language of a particular country. But scientific names are based on Latin, a universally used language that not too long ago was well known by most scholars.

Check Your Progress 1.2

1. Explain how natural selection results in new adaptations within a species.
2. List the levels of taxonomic classification from most inclusive to least inclusive.
3. Describe the differences that might be used to distinguish among the various kingdoms of domain Eukarya.

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 human beings 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. 1.11) 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 "seeing what happens."

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, chance 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

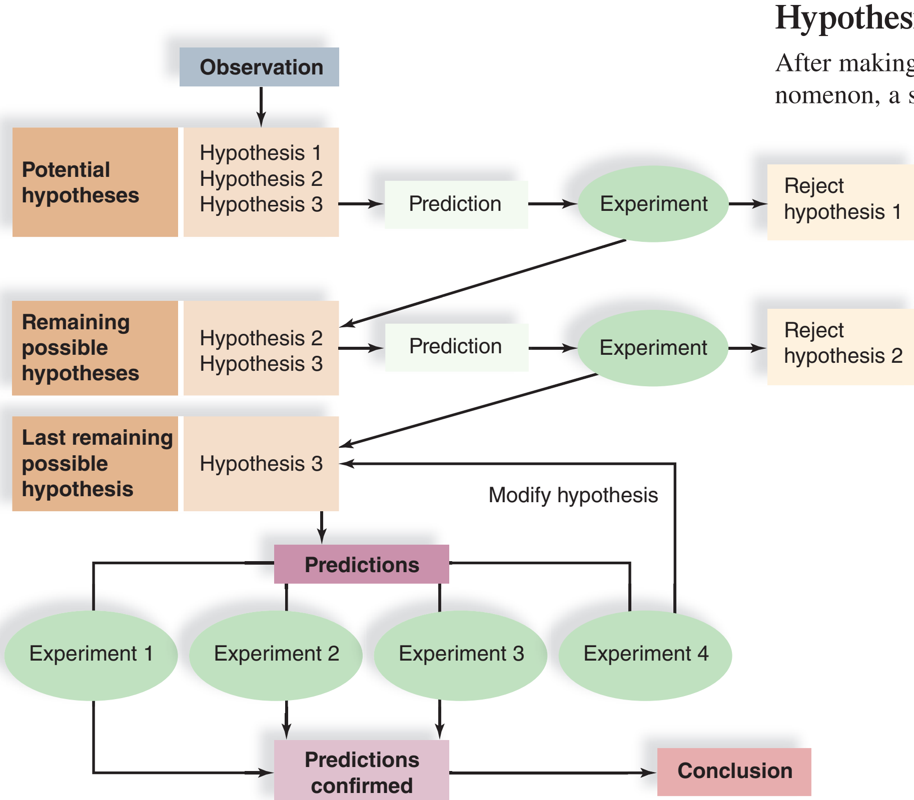


Figure 1.11 Flow diagram for the scientific method. On the basis of new and/or previous observations, a scientist formulates a hypothesis. The hypothesis is used to develop predictions to be tested by further experiments and/or observations, and new data either support or do not support the hypothesis. 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.