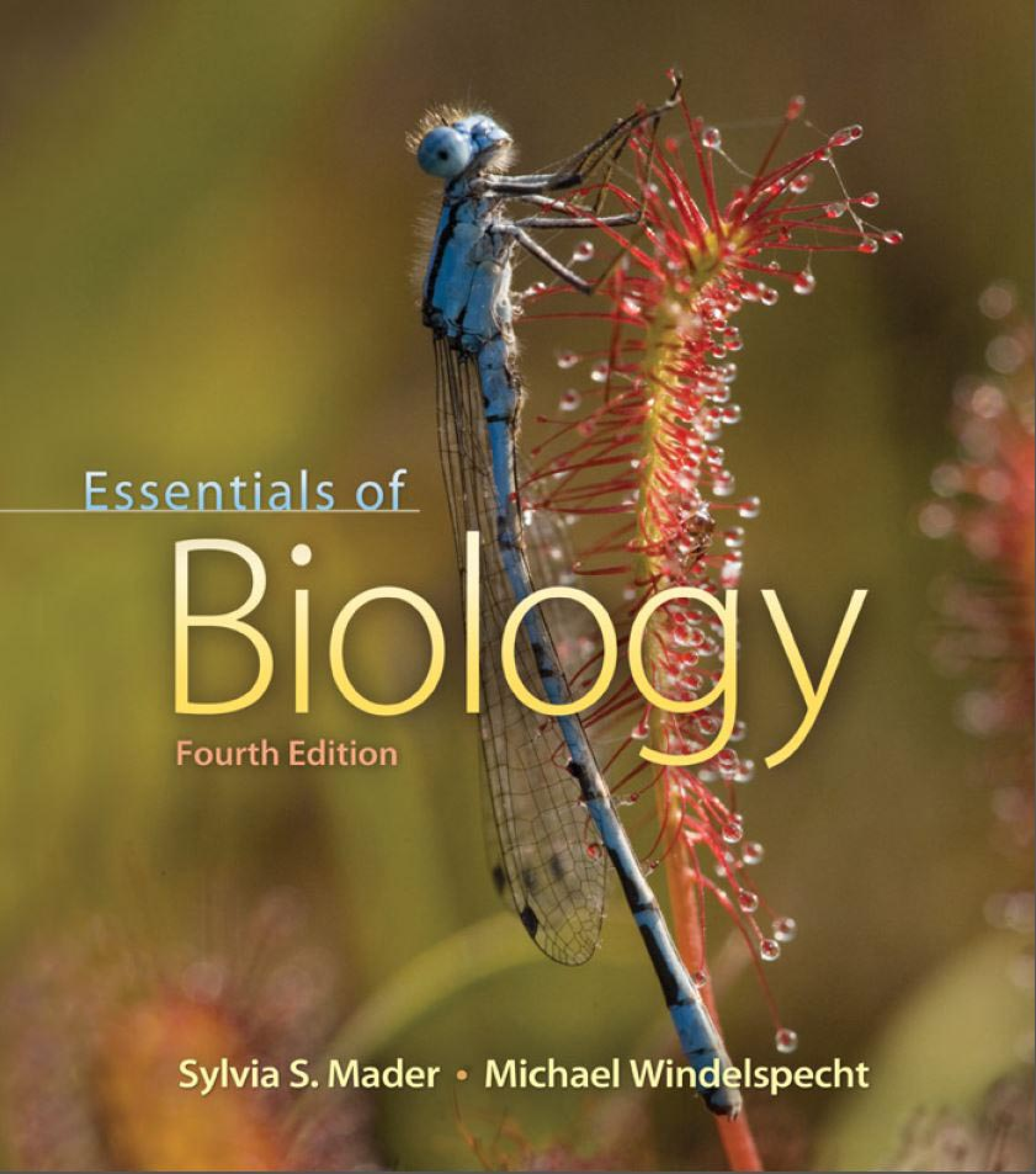

Essentials of

Biology

Fourth Edition

Sylvia S. Mader • Michael Windelspecht

Essentials of Biology

Fourth Edition

Sylvia S. Mader

Michael Windelspecht

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Brief Contents

About the Authors

Dr. 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 Mathew Seminars. Her ability to reach out to science-shy students led to the writing of her first text, *Inquiry into Life,* that is now in its fourteenth edition. Highly acclaimed for her crisp and entertaining writing style, her books have become models for others who write in the field of biology.

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.

Dr. 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 non-majors 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.

Preface

Essentials of Biology Fourth Edition, provides non-science majors with a fundamental understanding of the science of biology. The overall focus of this edition addresses the learning styles of modern students, and in the process, increases their understanding of the importance of science in their lives.

The authors identified several goals that guided the preparation of this new edition:

- **Pedagogy**—integration of new features and reorganization of chapter content to align the text with teaching practices.
- **Relevancy**—new chapter openers, Connection readings, and media to interest the modern student.
- **Adaptive Learning**—*Essentials of Biology* is the flagship for the next generation of adaptive learning products. Throughout this text, the authors have used student data from the LearnSmart product in their review of the content and chapter structure. Refer to pages viii and ix for more information on McGraw-Hill's LearnSmart Advantage products.
- **Media**—full integration of media assets, including 3D animations and LearnSmart Lab exercises, into each chapter.

Pedagogy

- Redesign of the Connections feature helps students recognize how the content is not only connected within the chapter, but how it relates to other areas of the text.
- Restructuring of the genetics unit (Unit II) aligns similar content within a single chapter.
  - Chapter 10 includes all aspects of inheritance, from Mendel to sex-linked inheritance, and describes how Mendel's laws apply to humans.
  - Chapter 11 progresses from the structure of DNA to the regulation of genes.
  - Chapter 12 discusses the basics of biotechnology, stem cells, and the importance of genomics and bioinformatics.
  - Chapter 13 begins with the discussion of genes and mutations, and then progresses through chromosomal mutations, before concluding with genetic counseling and gene therapy.
- Reduction in the number of bold-faced terms helps students focus on terms that are needed to understand the broader scope of biology. Italicized terms indicate concepts that are important within the context of a chapter.

Relevancy

- The majority of the chapter openers in the text have been rewritten to introduce relevancy to the chapter. The authors chose topics that would be of interest to a non-science major, and represent what would typically be found on a major news source.
- The Connections features provide interesting insights into how the content relates to the everyday world.
- The authors have created a Facebook site and website, Ricochet Science, that provides updates on news and stories that are interesting to non-science majors. Both sites feature videos to assist the student in recognizing the relevancy of what they are learning in the classroom.

Ricochet Science

Connections

New Connections readings can be found throughout the text. This feature is designed to help students understand the relevancy of biological concepts to their everyday lives. The Connections are organized by Health, Scientific Inquiry, and Evolution. Refer to the inside back cover for a complete listing.

Connections: Scientific Inquiry

Do "magical" plants really exist?

Strange and poisonous plants have been made famous by popular series such as *Harry Potter* and *The Hunger Games*. But do these types of plants really exist? Yes! Mandrake roots look like a human body, and giant hogweed leaves will cause painful blisters to sprout on the skin. Cuckoopint ("bloody man's finger") will cause the tongue to swell, and the black berries of the deadly nightshade are indeed lethal.

Connections: Scientific Inquiry

How closely is *Homo sapiens* related to Neandertals?

In 2010, geneticists completed their first sequence analysis of the Neandertal genome. The results of this study revealed some very interesting facts regarding Neandertals and *Homo sapiens*. First, these two species were more genetically alike than previous thought. The initial analysis suggested that as few as 100 genes in *Homo sapiens* may show evidence of evolution since the Neanderthal-*sapiens* split, making the Neandertals one of our closest cousins. Second, some studies suggest that there is evidence that Neandertals and *H. sapiens* might have interbred. Although this is still being investigated, we know that these two species occupied overlapping territories in the Middle East and Europe for almost 14,000 years. Since Neandertals and *H. sapiens* were genetically similar, many scientists believe that interbreeding may have been possible, although research is continuing into other explanations for these similarities.

Media Integration

Throughout each chapter, there is full integration of content and animation, video, and audio assets. Virtually every section of the textbook is now linked to MP3 files, animations of biological processes, National Geographic videos, or ScienCentral videos.

Media Study Tools

connect BIOLOGY

www.mhhe.com/maderessentials4

Enhance your study of this chapter with study tools and practice tests. Also ask your instructor about the resources available through ConnectPlus, including the media-rich eBook, interactive learning tools, and animations.

Animations	MP3 Files
7.1 How the NAD^+ Works **7.2** How Glycolysis Works **7.4** How the Krebs Cycle Works • Proton Pump • Electron Transport System and ATP Synthesis	**7.1** Cellular Respiration

3D Animation Cellular Respiration — For an interactive exploration of the processes involved in cellular respiration, take a moment to review McGraw-Hill's 3D animation "Cellular Respiration."

MP3 files. These three-to-five minute audio files not only serve as a review of the material in the chapter, but also assist the student in the pronunciation of scientific terms.

Animations. Drawing on McGraw-Hill's vast library of animations, the authors have selected animations that will enhance the student's understanding of complex biological processes.

Videos. Two different types of movies are integrated into this edition of the text. The ScienCentral videos are short news clips highlighting scientific discoveries. The National Geographic videos provide the student with a glimpse of the complexity of life that normally would not be possible in the classroom.

3D Animations. Many of the chapters contain icons for McGraw-Hill's 3D animation series. The 12 videos in this series provide a visual resource for teaching complex concepts, from photosynthesis to the carbon cycle.

LEARNSMART LABS™

McGraw-Hill LearnSmart Labs™. At the end of selected chapters, icons indicate the presence of new LearnSmart Labs activities that provide a highly realistic and adaptive simulated lab experience that allows students to "do and think" like a scientist via exploration and execution of the scientific method.

ENGAGE

LEARNSMART LABS™

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

- Evidence of Evolution
- Natural Selection

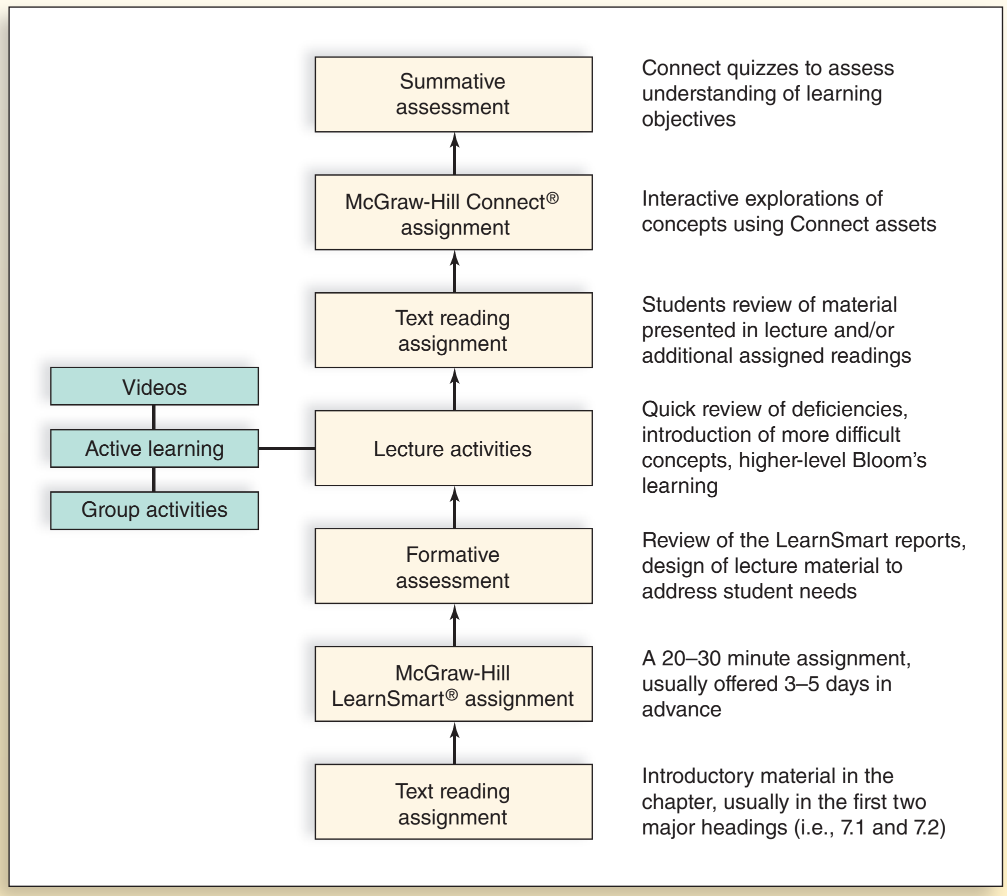
Thinking Critically About the Concepts

1. The human appendix, a vestigial extension of the large intestine, is homologous to a structure called a caecum in other mammals. A caecum, generally larger than our appendix, houses bacteria that aid in digesting cellulose, the main component of plants. How might the presence of the appendix be used to show our common ancestry with other mammals, and what might it tell us about the dietary history of humans?
2. Geneticists compare DNA base sequences among organisms and from these data determine a gene's rate of evolution. Different genes have been found to evolve at different rates. Explain why some genes have faster rates of evolution than other genes as populations adapt to their environments.
3. Both Darwin and Wallace, while observing life on islands, concluded that natural selection is the mechanism for biological evolution. The Hawaiian and nearby islands once had at least 50 species of honeycreepers, and they lived nowhere else on Earth. Natural selection occurs everywhere and in all species. What characteristics of islands allow the outcome of natural selection to be so obvious?

Using *Essentials of Biology* in Flipped Classes

This text, and the wealth of digital resources that accompany this text, are ideal assets for instructors who wish to move towards some of the newer teaching philosophies, or who are developing an online course. The concise nature of this text provides students with a fundamental understanding of key concepts, which may then be expanded upon by the instructor. The graphic below is designed to provide a sample of how the *Essentials of Biology,* Fourth Edition assets may be used in these environments. For additional strategies and tutorials to assist in the development of these classes, visit Dr. Windelspecht's website at RicochetScience.com

In a flipped classroom, the students do part of their work before coming to class, thus allowing the instructor to dedicate class time to relevancy or current event topics, or to introduce higher-level learning activities (Bloom's Application or Create levels).



The LearnSmart Advantage

LEARNSMART®

LearnSmart is the only truly adaptive learning system that intelligently identifies course content students have not yet mastered and maps out personalized study plans for their success**.**

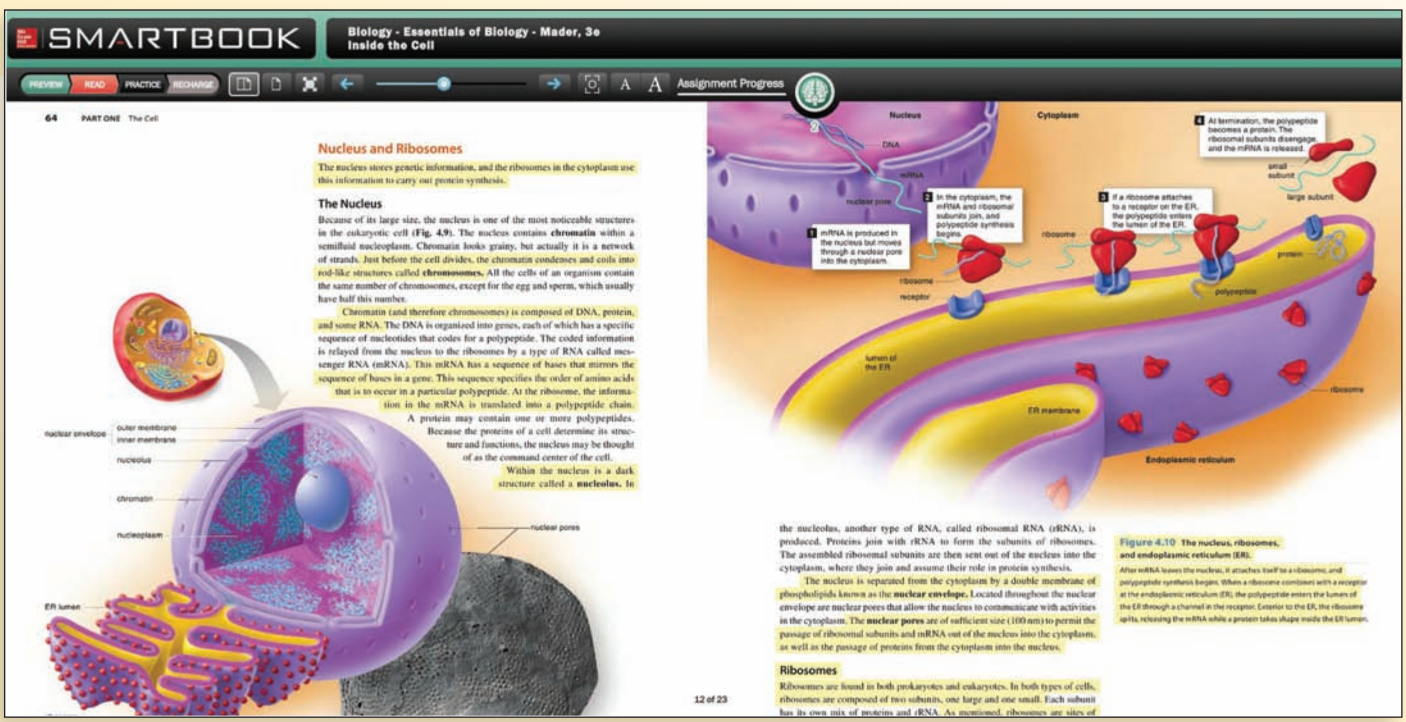
When LearnSmart has identified a specific subject area where the student is struggling, he or she is given a "time out" and directed to the textbook section and learning objective for remediation.

Dynamically generated reports document student progress and areas for additional reinforcement, offering at-a-glance views of their strengths and weaknesses.

SMARTBOOK™

Powered by an intelligent diagnostic and adaptive engine, **SmartBook** facilitates the reading process by identifying what content a student knows and doesn't know through adaptive assessments.

As the student reads, the reading material constantly adapts to ensure the student is focused on the content he or she needs the most to close any knowledge gaps.



The Evolution of Learning

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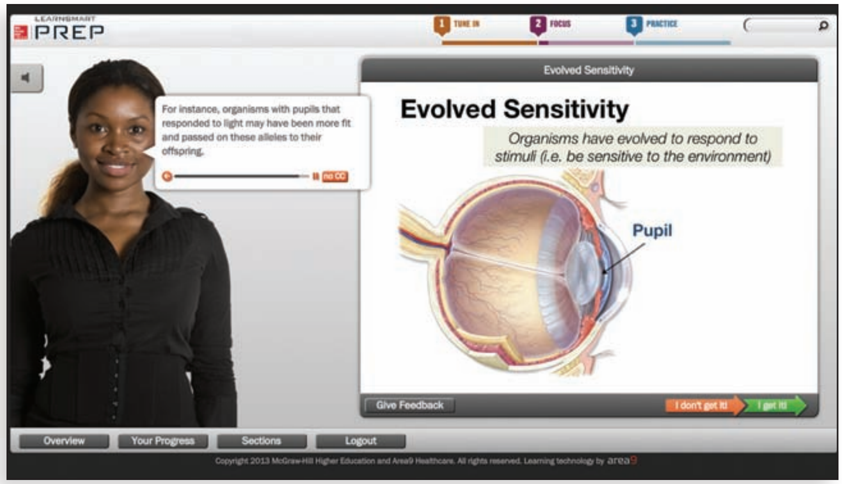
LEARNSMART PREP™

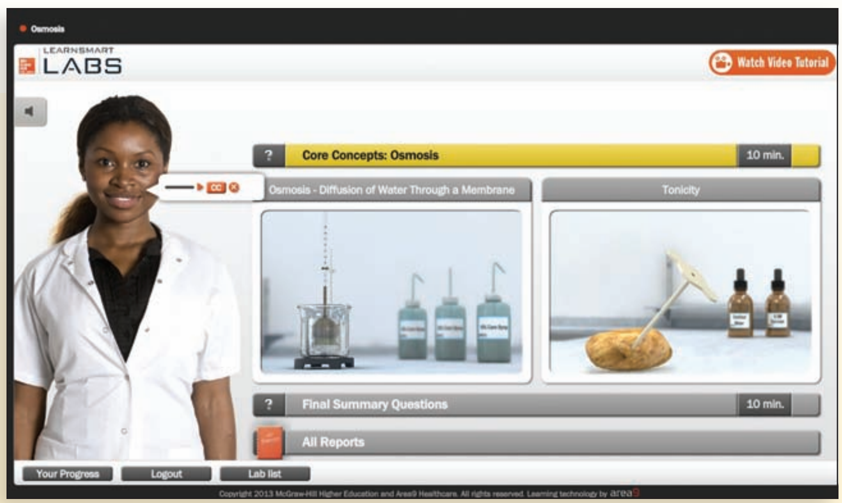
LearnSmart Prep quickly and efficiently prepares students for a college-level course. Prep uses a set of diagnostic questions to help identify what a student knows and doesn't know. It then provides a unique learning plan focused on helping the student master the basic skills and concepts he or she needs the most before entering the classroom.



LEARNSMART LABS™

LearnSmart Labs is a super-adaptive simulated lab experience that brings meaningful scientific exploration to students. Through a series of adaptive questions, LearnSmart Labs identifies a student's knowledge gaps and provides resources to quickly and efficiently close those gaps. Once the student has mastered the necessary basic skills and concepts, they engage in a highly realistic simulated lab experience that allows for mistakes and the execution of the scientific method.

Whether your need is to overcome the logistical challenges of a traditional lab, provide better lab prep, improve student performance, or make your online experience one that rivals the real world, LearnSmart Labs accomplishes it all.



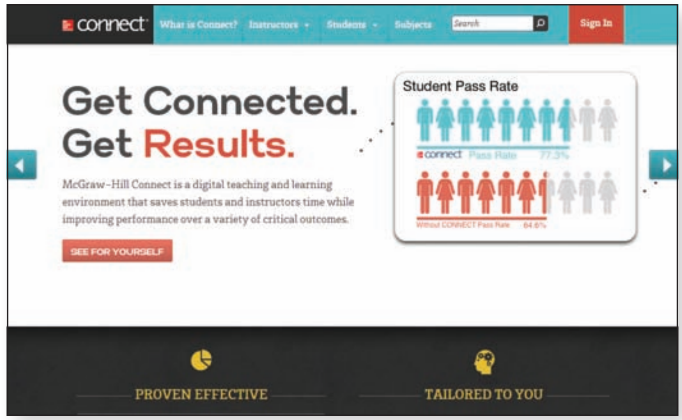
AN INNOVATIVE SUITE OF **ADAPTIVE LEARNING PRODUCTS** FUELED BY INTELLIGENT AND PROVEN LEARNING TECHNOLOGY

www.LearnSmartAdvantage.com

Teaching and Learning Tools

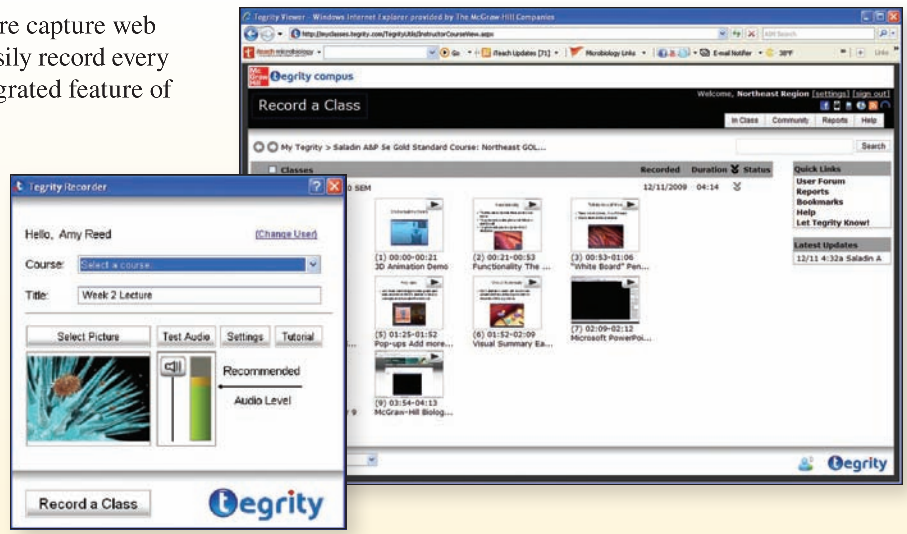
McGraw-Hill Connect® is a web-based assignment and assessment platform that gives students the means to better connect with coursework, instructors, and important concepts that they will need to know for success now and in the future.

McGraw-Hill Connect Plus® provides students with all the advantage of Connect Biology, plus a dynamic, media-rich eBook. To learn more visit **www.mcgrawhillconnect.com**



Tegrity Campus® is a lecture capture web service that allows you to easily record every class for every student. Tegrity is available as an integrated feature of Connect Biology and as a standalone.

- Make your classes available anytime, anywhere.
- Simple one-click recording. No IT assistance required.
- Students can search a word or phrase and be taken to the exact place in your lecture they need to view.



LEARNSMART®

Integrated within Connect and available as a standalone, **McGraw-Hill LearnSmart®** is the premier learning system designed to effectively assess a student's knowledge of course content. Through a series of adaptive questions, LearnSmart intelligently pinpoints concepts the student does not understand and maps out a personalized study plan for success. LearnSmart prepares students with a base of knowledge, allowing instructors to focus valuable class time on higher-level concepts.

New **SmartBook™** facilitates the reading process by identifying what content a student knows and doesn't know through adaptive assessments. As the student reads, the reading material constantly adapts to ensure the student is focused on the content he or she needs the most to close any knowledge gaps.

See pages viii and ix for more information about the **LearnSmart Advantage™** suite of adaptive tools or go to **www.LearnSmartAdvantage.com.**

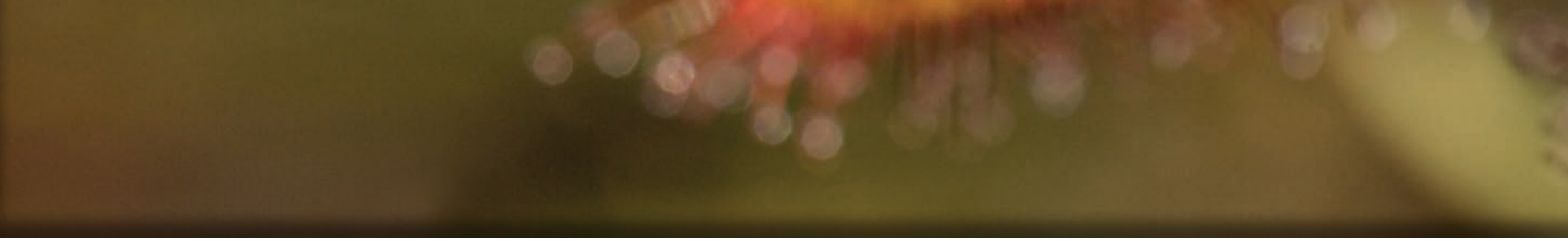
The **Best** of **Both Worlds**

McGraw-Hill and Blackboard Inc. teamed up to deliver the first to market integrated course solution which offers the deepest integration of publisher content within an LMS for Blackboard versions 8.0, 9.0, and 9.1.

Connect Single Sign-on. A single login and single environment provide seamless access to all course resources—all McGraw-Hill's resources are available within the Blackboard Learn platform.

Deep Integration. One-click access to McGraw-Hill Connect assignments and tools—all from within Blackboard Learn™.

One Gradebook. Automatic grade synchronization with Blackboard gradebook. All grades for McGraw-Hill assignments are recorded in the Blackboard gradebook automatically.



Instructor Resources

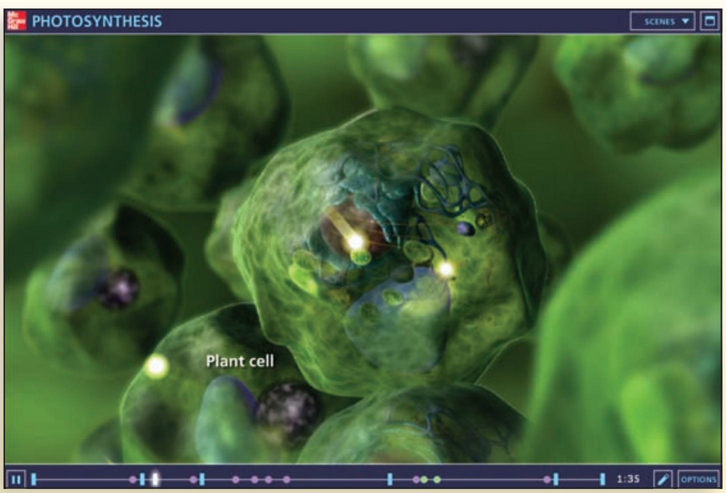
Connect® Biology provides easy access to the following resources:

Presentation Tools

- Image PowerPoints®
- Lecture PowerPoints with animations
- Animation PowerPoints
- Labeled and unlabeled JPEG files of art, photos, and tables from the textbook.
- Instructor's Manual containing chapter outlines, lecture enrichment ideas, and discussion questions.
- Laboratory Resource Guide to accompany the *Essentials of Biology Laboratory Manual*

Animations for a New Generation

Dynamic, 3D animations of key biological processes bring an unprecedented level of control to the classroom. Innovative features keep the emphasis on teaching rather than entertaining.



Computerized Test Bank

A comprehensive bank of test questions is provided within a computerized test bank powered by McGraw-Hill's flexible electronic testing program, **EZ Test Online.** A new tagging scheme allows you to sort questions by Bloom's difficulty level, learning outcome, topic, and section. With EZ Test Online, instructors can select questions from multiple McGraw-Hill test banks or author their own, and then either print the test for paper distribution or give it online.

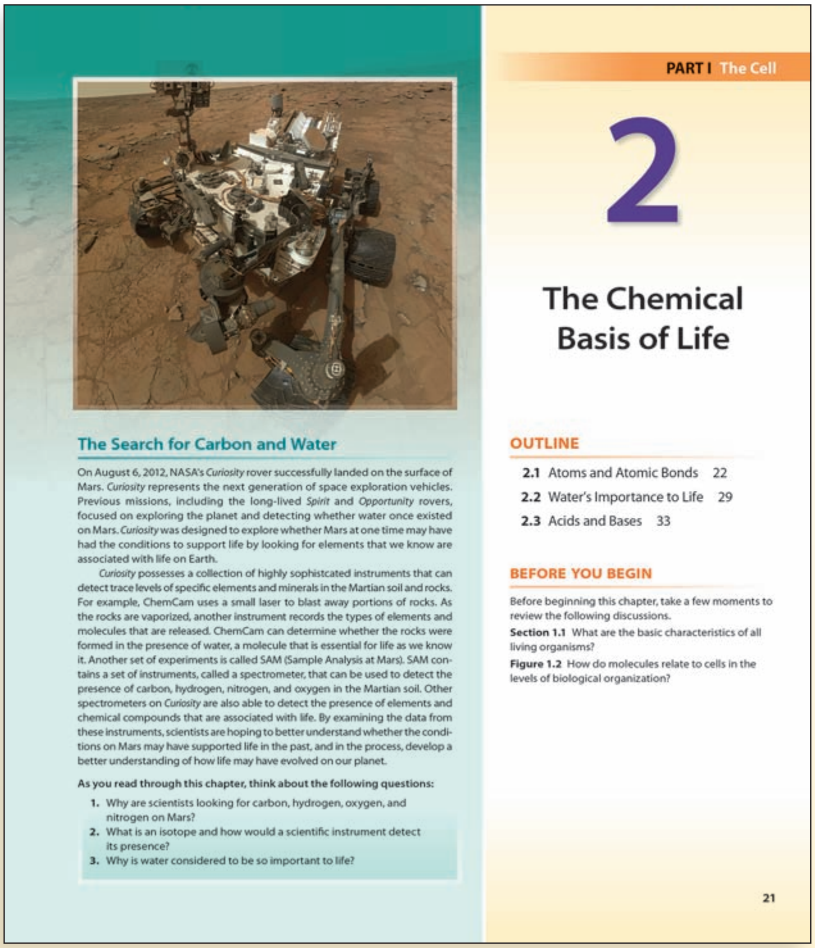
Laboratory Manual

The *Essentials of Biology Laboratory Manual* is written by Dr. Sylvia Mader. Every laboratory has been written to help students learn the fundamental concepts of biology and the specific content of the chapter to which the lab relates, as well as gain a better understanding of the scientific method.

Create

Design your teaching resources to match the way you teach! With McGraw-Hill Create™ you can easily rearrange chapters, combine material from other content sources, and quickly upload content you have written. Access thousands of leading McGraw-Hill textbooks for content that fits your objectives and arrange your book to fit your teaching style. Create even allows you to personalize your book's appearance by selecting the cover and adding your name, school, and course information. Order a Create book and you'll receive a complimentary print review copy in 3–5 business days or a complimentary electronic review copy (eComp) via email in minutes. Go to **www.mcgrawhillcreate.com** today and register to experience how McGraw-Hill Create empowers you to teach *your* students *your* way.

A Student's Guide to Using This Textbook


PART I The Cell

2

The Chemical Basis of Life

The Search for Carbon and Water

On August 6, 2012, NASA's *Curiosity* rover successfully landed on the surface of Mars. *Curiosity* represents the next generation of space exploration vehicles. Previous missions, including the long-lived *Spirit* and *Opportunity* rovers, focused on exploring the planet and detecting whether water once existed on Mars. *Curiosity* was designed to explore whether Mars at one time may have had the conditions to support life by looking for elements that we know are associated with life on Earth.

Curiosity possesses a collection of highly sophistcated instruments that can detect trace levels of specific elements and minerals in the Martian soil and rocks. For example, ChemCam uses a small laser to blast away portions of rocks. As the rocks are vaporized, another instrument records the types of elements and molecules that are released. ChemCam can determine whether the rocks were formed in the presence of water, a molecule that is essential for life as we know it. Another set of experiments is called SAM (Sample Analysis at Mars). SAM contains a set of instruments, called a spectrometer, that can be used to detect the presence of carbon, hydrogen, nitrogen, and oxygen in the Martian soil. Other spectrometers on *Curiosity* are also able to detect the presence of elements and chemical compounds that are associated with life. By examining the data from these instruments, scientists are hoping to better understand whether the conditions on Mars may have supported life in the past, and in the process, develop a better understanding of how life may have evolved on our planet.

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

1. Why are scientists looking for carbon, hydrogen, oxygen, and nitrogen on Mars?
2. What is an isotope and how would a scientific instrument detect its presence?
3. Why is water considered to be so important to life?

OUTLINE

BEFORE YOU BEGIN

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

Section 1.1 What are the basic characteristics of all living organisms?

Figure 1.2 How do molecules relate to cells in the levels of biological organization?

21

Chapter Outline

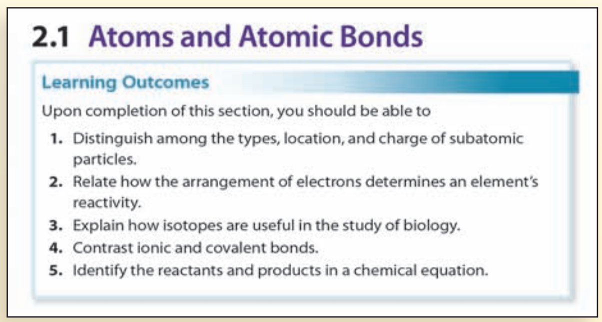
Lists the major sections that will be discussed in the chapter.

Before You Begin

Links the content of the chapter with material from earlier in the text. The questions designate important topics that you should understand before proceeding into the chapter.

Learning Outcomes

Provide you with an overview of what you are to know. Your instructor can assign activities through Connect® to help you achieve these outcomes.


2.1 Atoms and Atomic Bonds

Learning Outcomes

Upon completion of this section, you should be able to

1. Distinguish among the types, location, and charge of subatomic particles.
2. Relate how the arrangement of electrons determines an element's reactivity.
3. Explain how isotopes are useful in the study of biology.
4. Contrast ionic and covalent bonds.
5. Identify the reactants and products in a chemical equation.

Media Integration

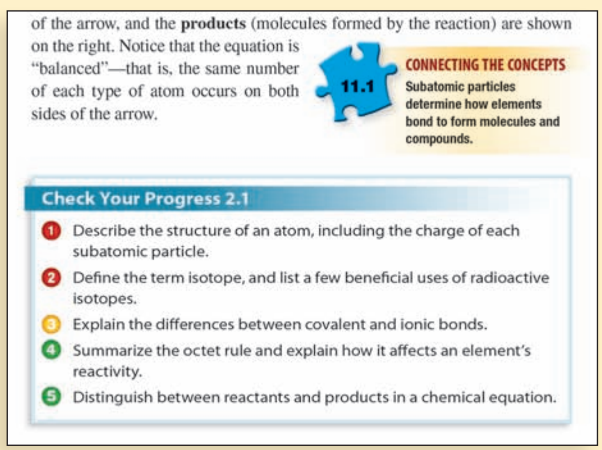
Enhances your study of biology with media. Go to www.mhhe.com/maderessentials4 to access the animations, videos, and MP3 files referenced throughout this book. Ask your instructor about related quizzes that are available through Connect® Biology.

Revised Connecting the Concepts

This new feature is designed to not only demonstrate to the student how the content within a chapter is connected, but also to link the chapter content to other areas of the text. The goal is to present biology as a discipline, and not simply a collection of facts and processes.

Check Your Progress

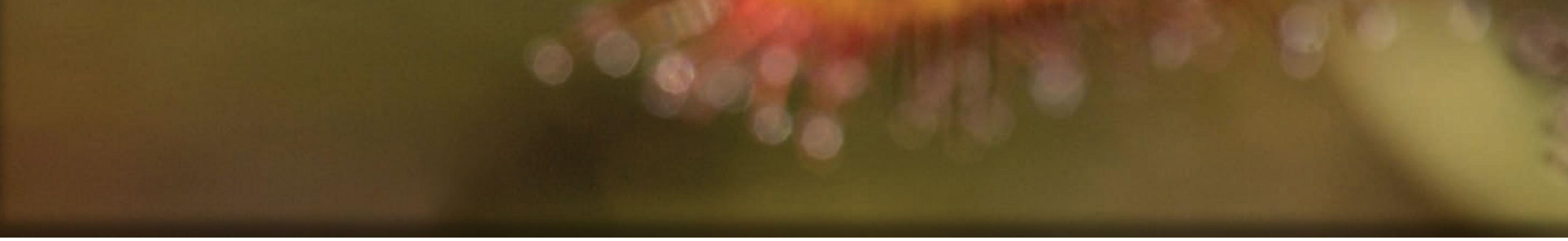
Questions at the end of each section help you assess and/or apply your understanding of the material in the section. The questions progress in difficulty (red, yellow, green) to ensure you are going beyond memorization of content.


of the arrow, and the **products** (molecules formed by the reaction) are shown on the right. Notice that the equation is "balanced"—that is, the same number of each type of atom occurs on both sides of the arrow.

CONNECTING THE CONCEPTS 11.1 Subatomic particles determine how elements bond to form molecules and compounds.

Check Your Progress 2.1

1. Describe the structure of an atom, including the charge of each subatomic particle.
2. Define the term isotope, and list a few beneficial uses of radioactive isotopes.
3. Explain the differences between covalent and ionic bonds.
4. Summarize the octet rule and explain how it affects an element's reactivity.
5. Distinguish between reactants and products in a chemical equation.



Media Study Tools

Provide a link to the *Essentials of Biology* website, that contains practice tests, animations, and videos organized and integrated by chapter to help you succeed in your study of biology. The ConnectPlus® platform provides a media-rich eBook, interactive learning tools, and access to the LearnSmart® system for enhanced student performance.

Summary

Provides an excellent overview of the chapter concepts using concise summaries, summary tables, and key illustrations.

Revised Key Terms

In this edition, the key, bold-faced terms in the chapter are integrated into the Summarize material at the end of the chapter. This helps the student understand the importance of the term in the context of the chapter content.

LearnSmart Labs™

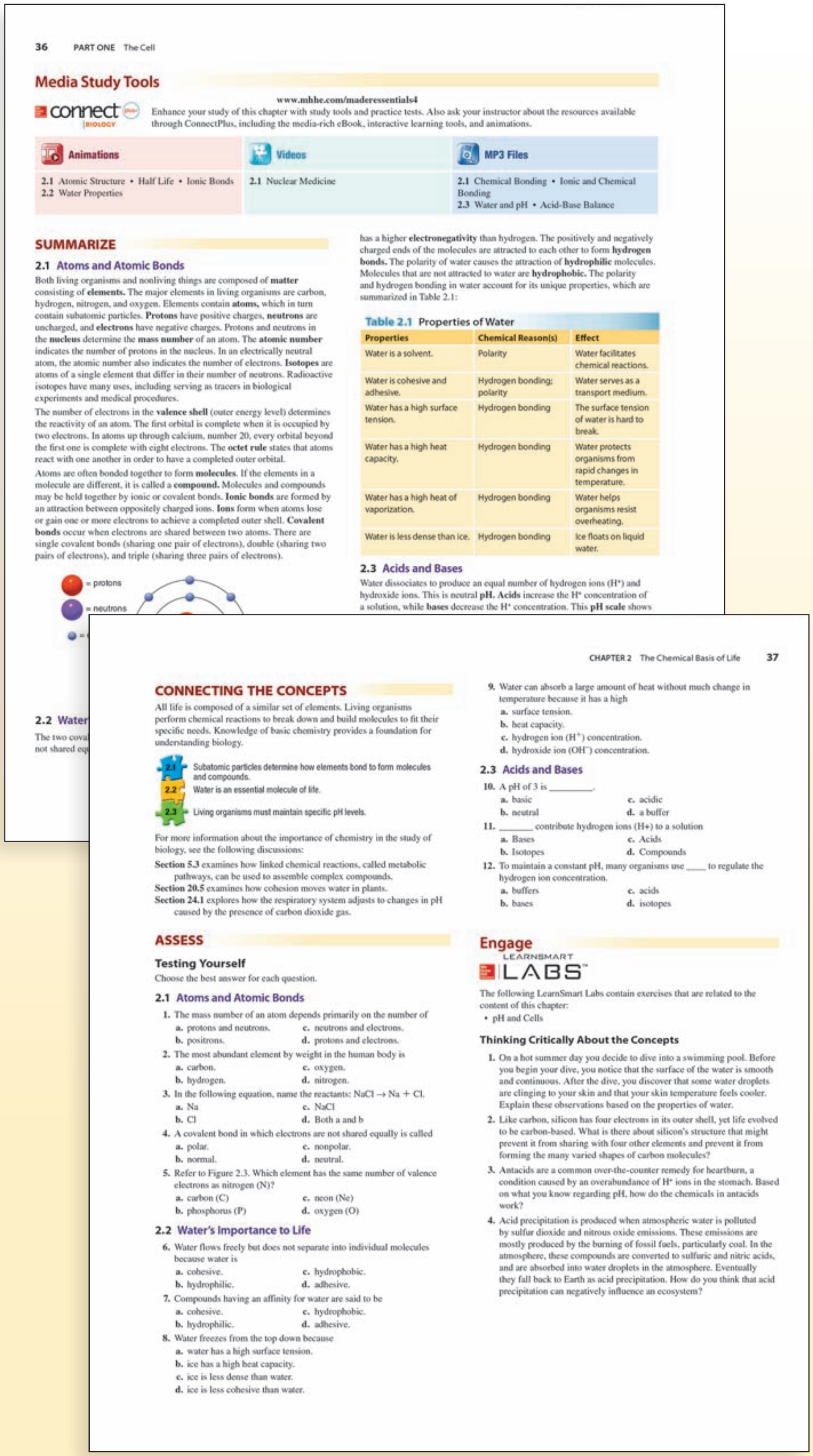
Allow you to investigate topics associated with the content of the chapter from a scientific perspective.

Revised Thinking Critically About the Concepts

Questions give you an opportunity to reason as a scientist. (See Appendix A for answers.) The questions in this section help you understand the process of scientific thinking by exploring topics that have a bioethical focus or are related to topics in the news.

Testing Yourself

Questions help you review material and prepare for tests. (See Appendix A for answers.) These are arranged by section for easy review.



36 PART ONE The Cell

Media Study Tools

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connect plus BIOLOGY Enhance your study of this chapter with study tools and practice tests. Also ask your instructor about the resources available through ConnectPlus, including the media-rich eBook, interactive learning tools, and animations.

Animations	Videos	MP3 Files
2.1 Atomic Structure • Half Life • Ionic Bonds 2.2 Water Properties	2.1 Nuclear Medicine	2.1 Chemical Bonding • Ionic and Chemical Bonding 2.3 Water and pH • Acid-Base Balance

SUMMARIZE

2.1 Atoms and Atomic Bonds

Both living organisms and nonliving things are composed of **matter** consisting of **elements.** The major elements in living organisms are carbon, hydrogen, nitrogen, and oxygen. Elements contain **atoms,** which in turn contain subatomic particles. **Protons** have positive charges, **neutrons** are uncharged, and **electrons** have negative charges. Protons and neutrons in the **nucleus** determine the **mass number** of an atom. The **atomic number** indicates the number of protons in the nucleus. In an electrically neutral atom, the atomic number also indicates the number of electrons. **Isotopes** are atoms of a single element that differ in their number of neutrons. Radioactive isotopes have many uses, including serving as tracers in biological experiments and medical procedures.

The number of electrons in the **valence shell** (outer energy level) determines the reactivity of an atom. The first orbital is complete when it is occupied by two electrons. In atoms up through calcium, number 20, every orbital beyond the first one is complete with eight electrons. The **octet rule** states that atoms react with one another in order to have a completed outer orbital.

Atoms are often bonded together to form **molecules.** If the elements in a molecule are different, it is called a **compound.** Molecules and compounds may be held together by ionic or covalent bonds. **Ionic bonds** are formed by an attraction between oppositely charged ions. **Ions** form when atoms lose or gain one or more electrons to achieve a completed outer shell. **Covalent bonds** occur when electrons are shared between two atoms. There are single covalent bonds (sharing one pair of electrons), double (sharing two pairs of electrons), and triple (sharing three pairs of electrons).

= protons
= neutrons

2.2 Water

The two coval

not shared eq

has a higher **electronegativity** than hydrogen. The positively and negatively charged ends of the molecules are attracted to each other to form **hydrogen bonds.** The polarity of water causes the attraction of **hydrophilic** molecules. Molecules that are not attracted to water are **hydrophobic.** The polarity and hydrogen bonding in water account for its unique properties, which are summarized in Table 2.1:

Table 2.1 Properties of Water

Properties	Chemical Reason(s)	Effect
Water is a solvent.	Polarity	Water facilitates chemical reactions.
Water is cohesive and adhesive.	Hydrogen bonding; polarity	Water serves as a transport medium.
Water has a high surface tension.	Hydrogen bonding	The surface tension of water is hard to break.
Water has a high heat capacity.	Hydrogen bonding	Water protects organisms from rapid changes in temperature.
Water has a high heat of vaporization.	Hydrogen bonding	Water helps organisms resist overheating.
Water is less dense than ice.	Hydrogen bonding	Ice floats on liquid water.

2.3 Acids and Bases

Water dissociates to produce an equal number of hydrogen ions (H^+) and hydroxide ions. This is neutral **pH. Acids** increase the H^+ concentration of a solution, while **bases** decrease the H^+ concentration. This **pH scale** shows

CHAPTER 2 The Chemical Basis of Life 37

CONNECTING THE CONCEPTS

All life is composed of a similar set of elements. Living organisms perform chemical reactions to break down and build molecules to fit their specific needs. Knowledge of basic chemistry provides a foundation for understanding biology.

2.1 Subatomic particles determine how elements bond to form molecules and compounds.
2.2 Water is an essential molecule of life.
2.3 Living organisms must maintain specific pH levels.

For more information about the importance of chemistry in the study of biology, see the following discussions:

Section 5.3 examines how linked chemical reactions, called metabolic pathways, can be used to assemble complex compounds.
Section 20.5 examines how cohesion moves water in plants.
Section 24.1 explores how the respiratory system adjusts to changes in pH caused by the presence of carbon dioxide gas.

ASSESS

Testing Yourself

Choose the best answer for each question.

2.1 Atoms and Atomic Bonds

1. The mass number of an atom depends primarily on the number of
   a. protons and neutrons. c. neutrons and electrons.
   b. positrons. d. protons and electrons.
2. The most abundant element by weight in the human body is
   a. carbon. c. oxygen.
   b. hydrogen. d. nitrogen.
3. In the following equation, name the reactants: $NaCl \rightarrow Na + Cl$.
   a. Na c. NaCl
   b. Cl d. Both a and b
4. A covalent bond in which electrons are not shared equally is called
   a. polar. c. nonpolar.
   b. normal. d. neutral.
5. Refer to Figure 2.3. Which element has the same number of valence electrons as nitrogen (N)?
   a. carbon (C) c. neon (Ne)
   b. phosphorus (P) d. oxygen (O)

2.2 Water's Importance to Life

6. Water flows freely but does not separate into individual molecules because water is
   a. cohesive. c. hydrophobic.
   b. hydrophilic. d. adhesive.
7. Compounds having an affinity for water are said to be
   a. cohesive. c. hydrophobic.
   b. hydrophilic. d. adhesive.
8. Water freezes from the top down because
   a. water has a high surface tension.
   b. ice has a high heat capacity.
   c. ice is less dense than water.
   d. ice is less cohesive than water.
9. Water can absorb a large amount of heat without much change in temperature because it has a high
   a. surface tension.
   b. heat capacity.
   c. hydrogen ion (H^+) concentration.
   d. hydroxide ion (OH^-) concentration.

2.3 Acids and Bases

10. A pH of 3 is ________.
    a. basic c. acidic
    b. neutral d. a buffer
11. ______ contribute hydrogen ions (H+) to a solution
    a. Bases c. Acids
    b. Isotopes d. Compounds
12. To maintain a constant pH, many organisms use ____ to regulate the hydrogen ion concentration.
    a. buffers c. acids
    b. bases d. isotopes

Engage

LEARNSMART LABS™

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

Thinking Critically About the Concepts

1. On a hot summer day you decide to dive into a swimming pool. Before you begin your dive, you notice that the surface of the water is smooth and continuous. After the dive, you discover that some water droplets are clinging to your skin and that your skin temperature feels cooler. Explain these observations based on the properties of water.
2. Like carbon, silicon has four electrons in its outer shell, yet life evolved to be carbon-based. What is there about silicon's structure that might prevent it from sharing with four other elements and prevent it from forming the many varied shapes of carbon molecules?
3. Antacids are a common over-the-counter remedy for heartburn, a condition caused by an overabundance of H^+ ions in the stomach. Based on what you know regarding pH, how do the chemicals in antacids work?
4. Acid precipitation is produced when atmospheric water is polluted by sulfur dioxide and nitrous oxide emissions. These emissions are mostly produced by the burning of fossil fuels, particularly coal. In the atmosphere, these compounds are converted to sulfuric and nitric acids, and are absorbed into water droplets in the atmosphere. Eventually they fall back to Earth as acid precipitation. How do you think that acid precipitation can negatively influence an ecosystem?

Overview of Content Changes to *Essentials of Biology,* Fourth Edition

Chapter 1: Biology: The Science of Life contains a new chapter opener on the diversity of life. The chapter has been reorganized so that chemical cycling and energy flow is included in discussion on the characteristics of life. New figures have been included to describe the levels of biological organization (1.2) and the flow of the scientific method (1.8). A new table (1.2) describes the kingdoms and domains of life. A new application reading concerning how evolution affects individuals personally has been added. In addition, there is a new section (1.4) describing the challenges facing science.

Part I *The Cell*

Chapter 2: The Chemical Basis of Life contains a new chapter opener on NASA's search for water and carbon on Mars. The chapter now contains an increased focus on the reactants and products of chemical reactions and added content on hydrogen bonds and their role in the structure of water molecules. Applications on Japan's Fukushima nuclear power disaster and the environmental importance of the density of ice are now included. Figure 2.10 on the cohesion and adhesion of water molecules has been updated to include diagrams of water molecules flowing through vessels. New figures describe the properties of ice (2.12) and acidosis in humans (2.14). **Chapter 3: The Organic Molecules of Life** contains a more detailed discussion of the importance of functional groups and updated information on the Human Genome Project. **Chapter 4: Inside the Cell** has been reorganized so that the discussion of the plasma membrane (section 4.2) precludes the discussion of cell types (section 4.3). Additional focus on the characteristics common to all cells has been included in the chapter as well. **Chapter 5: The Dynamic Cell** begins with a new opener on capsaicin and membrane transport. A new application reading that addresses calorie needs is provided. A new 3D animation, "Membrane Transport" has been added. A new figure (5.11) describing facilitated diffusion has been added. **Chapter 6: Energy for Life** contains a new chapter opener relating fall leaf color changes to photosynthesis. Content has been adjusted to include a more direct focus on oxidation and reduction reactions. A new 3D animation, "Photosynthesis" has been added. **Chapter 7: Energy for Cells** begins with a new chapter opener on the metabolic needs of athletes. The chapter has been reorganized so that processes occurring outside the mitochondria (glycolysis and fermentation) are presented first in sections 7.2 and 7.3 respectively, followed by the processes occurring inside the mitochondria (section 7.4). A new figure (7.8) describes the electron transport chain. In addition, a new section (7.5) describes the metabolic fate of food.

Part II *Genetics*

Chapter 8: Cellular Reproduction starts with a new chapter opener on the genetics of breast cancer. The chapter has been reorganized so that mitosis and cytokinesis are included in discussion with the cell cycle in section 8.2. Content on the characteristics of cancer has been moved from Chapter 12 and is now included in sections 8.4 and 8.5. A new 3D animation, "Cell Cycle and Mitosis" has been provided. An application reading on transposons and cancer is now included in this chapter. In **Chapter 9: Sexual Reproduction,** a new chapter opener describes the relationship between meiosis and genetic variation. In addition, the chapter now contains a more direct focus on the role of meiosis in the human life cycle and a new application reading on where new alleles originate. The content has also been enhanced with the addition of a 3D animation, "Meiosis." **Chapter 10: Patterns of Inheritance** contains a new chapter opener on phenylketonuria. Content describing pedigrees and common genetic disorders has been moved from Chapter 13 to be included in section 10.2. Content describing gene linkage has been condensed and is now included in section 10.3. The discussion of sex-linked inheritance now includes a discussion of sex-linked disorders. A new application reading relating skin color and race is now included with the chapter. **Chapter 11: DNA Biology and Technology** begins with a new chapter opener on DNA. The content of the chapter has been revised significantly so that the discussion of mutations has been moved to Chapter 13. In addition, content discussing gene regulation, including the function of the lac operon, control of gene expression, euchromatin and heterochromatin, and the role of transcription factors in gene regulation has been moved from Chapter 12 and is now included in section 11.3. Figures describing tRNA structure and function (11.13), initiation (11.14), and elongation (11.15) have been revised for clarity of understanding. New figures describe termination (11.16) and gene expression in specialized cells (11.18). Application readings on the different genetic codes used by organisms and X-inactivation have been added. The chapter contains two new 3D animations, "DNA Replication" and "Molecular Biology of the Gene." Content describing biotechnology, genomics, and proteomics has been moved from Chapter 11 and has joined content describing stem cells, reproductive cloning, and therapeutic cloning in **Chapter 12: Biotechnology and Genomics**. Chapter 12 also includes a new chapter opener on the age of biotechnology. A new figure describes polymerase chain reactions (12.2). The chapter also contains new application readings describing how stem cells are used therapeutically and the safety of food products from cloned animals. **Chapter 13: Genetic Counseling** starts with a new chapter opener on Down syndrome. The chapter has been reorganized so that discussion of genes, gene mutations, and chromosomal mutations is presented first in sections 13.1 and 13.2 respectively, followed by a discussion of testing for genetic disorders and gene therapy in sections 13.3 and 13.4 respectively. A figure describing the varying effects of point mutations (13.2) has been added to the chapter.

Part III *Evolution*

Chapter 14: Darwin and Evolution now begins with a chapter opener on the evolution of MRSA. Figure 14.13 has been added to describe the evolution of tetrapods. A new 3D animation, "Mechanisms of Evolution" has also been included in this chapter. In **Chapter 15: Evolution on a Small Scale**, a new chapter opener now describes the evolution of the HIV virus. In addition, the 3D animation, "Mechanisms of Evolution" has been added to this chapter as well. **Chapter 16: Evolution on a Large Scale** starts with a new chapter opener on micro-frog species. New figures describe the history of life in 24 hours (16.11) and the DNA differences in organisms (16.17). The 3D animation, "Mechanisms of Evolution" has been included in this chapter.

Part IV *The Diversity of Life*

In **Chapter 17: The Microorganisms: Viruses, Bacteria, and Protists** a new opener on the H5N1 and H7N9 bird flu has been included. New figures describe the anatomy of an influenza virus (17.1) and the major groups of protists (17.20). A new application reading describing norovirus is now included. Content explaining the natural flora of humans and antibiotics has been included to the discussion of bacteria. Additional information on algae has also been included in this chapter. A table (17.1) has been included to describe the eukaryotic supergroups of protists. In **Chapter 18: Land Environment: Plants and Fungi**, a new chapter opener includes the evolutionary defense strategies of both peppers and fungi. A new application reading on pollinator strategies has been added. New content has been added to describe white nose syndrome, a fungal disease found in bats. **Chapter 19: Both Water and Land: Animals** now contains a new chapter opener on vertebrate diversity. Discussion of the evolution of humans has been adjusted to include an increased focus on the replacement model with additional descriptions of the Neandertals and Denisovans. A new figure (19.41) now describes the replacement model.

Part V *Plant Anatomy and Growth*

Chapter 20: Plant Anatomy and Growth has been reorganized so that content on plant cells and tissues (section 20.1) is presented before content on plant organs (20.2). Furthermore, discussion of plant organs has been consolidated to focus on the essential components only, including root and shoot systems and primary growth. Content describing the organization of leaves, stems, and roots has been consolidated from three separate sections into one section (20.3). Additional information on crop rotation by farmers has been included. New figures describe meristem cell division (20.1) and leaf structure (20.9). A new application reading describing "magical" plants as seen in popular media has been added. A new 3D animation, "Plant Transport," has also been included in this chapter. In **Chapter 21: Plant Responses and Reproduction** a new chapter opener on banana farming is included. Content of this chapter has been altered to include an increased focus on positive and negative gravitropism, additional information on genetic engineering, and the pharmaceutical industry. In addition, discussion of genetically modified plants has been updated to reflect current research findings and statistics. Additional figures have been added to the chapter, including plant hormone response (21.1), apical dominance (21.3), gravitropism (21.8), and transformation of plants (21.25). Figure 21.22 has been reworked to include more structures for asexual propagation. Table 21.2 has been updated to reflect most current uses of GM plants. A new application reading describing coconuts has been included as well.

Part VI *Animal Structure and Function*

Chapter 22: Being Organized and Steady contains a new chapter opener on the homeostatic requirements of pop icon Lady Gaga. Figure 22.6 has been revised to include a labeled microscope image of blood tissue. Content within the chapter now contains an increased overall focus on the importance of homeostasis. The chapter now contains the 3D animation "Homeostasis." In **Chapter 23: The Transport Systems**, a new chapter opener on heart disease is included. The chapter contains updated information on cardiovascular disease, reflecting current research findings and statistics. **Chapter 24: The Maintenance Systems** contains an updated chapter opener on asthma. Content within the chapter has been revised to include more information on emphysema and an increased focus on kidney function in humans. Content on kidney disease has been updated to reflect current research findings. Content within **Chapter 25: Human Nutrition** has been revised to include content on hyponatrimia and updated information describing the USDA MyPlate guidelines. Table 25.2 has been adjusted to include information on the glycemic index and figure 25.10 has been updated to reflect current MyPlate USDA guidelines. New applications reading on the glycemic index, bomb calorimeters, and the Paleolithic diet have been added to the chapter. **Chapter 26: Defenses Against Disease** has been revised to include an increased focus on overall function of the immune system and added content on the cells of the immune system. In addition, section 26.2 has been revised to provide a more direct discussion of the four steps of the inflammatory response. In addition, figure 26.3 has been revised for additional clarity describing the steps of the inflammatory response. In section 26.3, acquired immunity is now referred to as adaptive immunity. The chapter now contains a new application reading on curing AIDS. **Chapter 27: The Control Systems** now contains a new chapter opener on multiple sclerosis. Section 27.1 has been reorganized so that content describing the nervous systems of nonhumans is presented separately from content describing the nervous system of humans. In addition, content on diabetes in the U.S. has been updated to reflect current statistics. A table (27.1) has been added to summarize the hormones released from the different organs of the endocrine system. **Chapter 28: Sensory Input and Motor Output** contains a new chapter opener on the skeletal and muscular system functioning of Olympic sprinter Usain Bolt. Figures diagramming the human skeleton (28.14) and the major skeletal muscles (28.16) in the human body have been added. The 3D animation "Skeletal Muscle Contraction" has been included in this chapter. Content in **Chapter 29: Reproduction and Development** has been revised. The discussion of emergency contraception has been updated to reflect the most current products on the market and discussion of HPV has been added to the chapter.

Part VI *Ecology*

Chapter 30: Ecology and Populations contains a new chapter opener on human population growth. Statistics on current global population growth rates have been updated. Figure 30.7 has been revised to more clearly describe the environmental impacts of MDCs and LDCs. Statistics within the application reading on highest and lowest population densities has been updated. **Chapter 31: Communities and Ecosystems** contains a new opener on global climate change. A new application reading on ocean acidification has been included. A new figure (31.28) diagramming the major terrestrial ecosystems worldwide has also been added to the chapter. In **Chapter 32: Human Impact on the Biosphere**, a new chapter opener on the Emiquon floodplain restoration has been added. The chapter has been reorganized to include additional content on conservation biology (section 32.1). Content on biodiversity (section 32.2) is now presented before content describing natural resources and the environmental impact of their use (section 32.3). Content describing alternative forms of energy has been updated to reflect current statistics.

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Michael Windelspecht, Ph.D.
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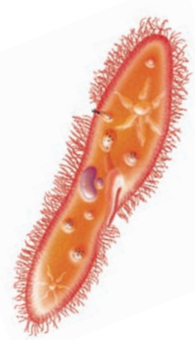

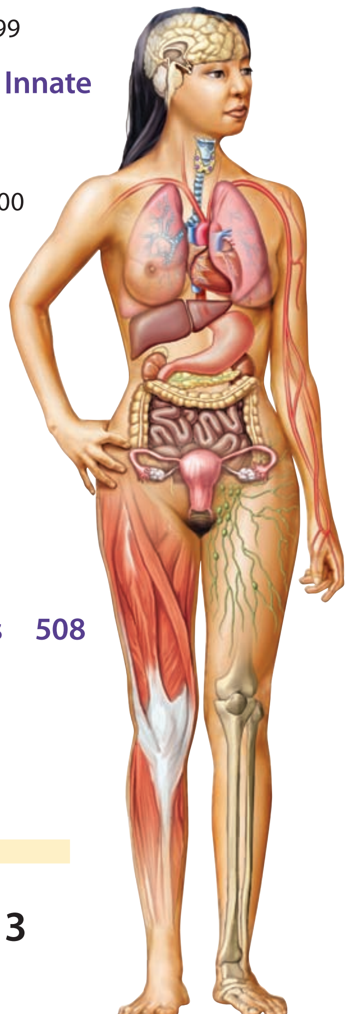

1

Biology: The Science of Life

OUTLINE

The Diversity of Life

Life on Earth takes on a staggering variety of forms, often with appearances and behaviors that may be strange to humans. As we will see in this chapter, one of the ways that biologists classify life is by species. So how many species are there on the planet? The truth is, we really don't know. While most scientists believe that there are probably as many as 15 million species on the planet, some estimate that there may be over 100 million different species. So far, around 2 million species have been identified, and most of those are insects.

However, new species are being discovered all the time. Some of those recent additions are shown here. The world's smallest reptile, *Brookesia micra*, found on Madagascar, is less than 1 inch long. The sneezing monkey, *Rhinopithecus strykeri*, was discovered in northeast Myanmar. While very rare, it is easy to locate in the forest, since it sneezes when it rains. Not all new species are rare—some have simply remained isolated from human contact, such as the Nepalese autumn poppy (*Meconopsis autumnalis*), which lives only at elevations about 10,000 feet in the Himalayas. As we will learn in this chapter, although life is diverse, it also shares a number of important characteristics.

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

1. What are the general characteristics that separate life from nonliving things?
2. How do species fit into the biological levels of organization?
3. What are some of the challenges facing science today?

Figure 1.1 **Diversity of life.**

Biology is the study of life in all of its diverse forms.

1.1 The Characteristics of Life

Learning Outcomes

Upon completion of this section, you should be able to

1. Explain the basic characteristics that are common to all living organisms.
2. Distinguish between the levels of biological organization.
3. Summarize how the terms *homeostasis, metabolism,* and *adaptation* all relate to living organisms.
4. Contrast chemical cycling and energy flow within an ecosystem.

As we observed in the chapter opener, life is diverse (**Fig. 1.1**). Life may be found everywhere on the planet, from thermal vents at the bottom of the ocean to the coldest reaches of Antarctica. **Biology** is the scientific study of life. Biologists study not only life's diversity but also the characteristics that are shared by all living organisms. These characteristics include levels of organization, the ability to acquire materials and energy, the ability to maintain an internal environment, the ability to respond to stimuli, the ability to reproduce and develop, and the ability to adapt and evolve to changing conditions. By studying these characteristics, we gain insight into the complex nature of life, which helps us distinguish living organisms from nonliving things. In the next sections, we will explore these characteristics in more detail.

MP3 Life Characteristics

Life Is Organized

The complex organization of life 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 (**Fig. 1.2**).

The majority of the organisms on the planet are single-celled. Plants, fungi, and animals are **multicellular** and are composed of many types of cells. In multicellular organisms, similar cells combine to form **tissues.** Tissues make up **organs,** as when various tissues combine to form a heart or a leaf. Organs work together in **organ systems;** for example, the heart and blood vessels form the cardiovascular system. Various organ systems work together within complex organisms.

The organization of life extends beyond the individual organism. All the members of a species (organisms with a similar structure that are capable of interbreeding) within a particular area belong to a **population.** When populations interact, such as the humans, zebras, and trees in Figure 1.2, they form a **community.** At the **ecosystem** level, communities interact with the physical environment (soil, atmosphere, etc.). Collectively, the ecosystems on the planet are called the **biosphere,** the zone of air, land, and water at the surface of the Earth where living organisms are found.

Video Coral Reef Ecosystem

Figure 1.2 Levels of biological organization.

The cell is the smallest unit of life. The biosphere includes all the life on the planet.

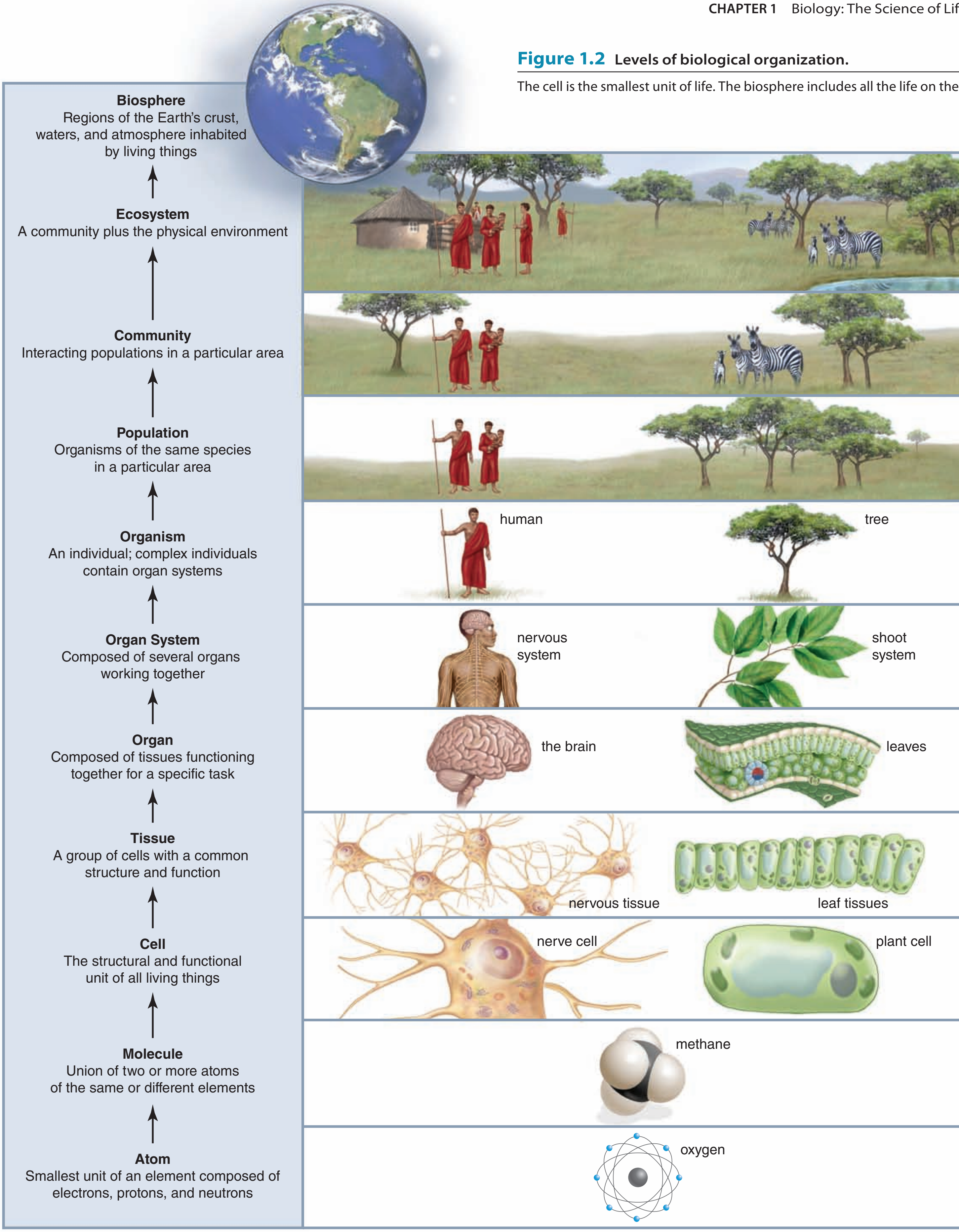

Figure 1.3 **Acquiring nutrient materials and energy.**

All organisms, including this hawk eating a fish, require nutrients and energy.

Life Requires Materials and Energy

Life from single cells to complex organisms (**Fig. 1.3**) cannot maintain their organization or carry on necessary activities without an outside source of materials and energy. Food provides nutrient molecules, which are used as building blocks or energy sources. **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** 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 nutrient molecules. For this reason, these organisms are commonly called producers. Animals and plants get energy by metabolizing nutrient molecules made by the producers.

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) 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.

Video Tallgrass Prairie Ecosystem

Living Organisms Maintain an Internal Environment

For metabolic processes to continue, living organisms need to keep themselves stable with regard to temperature, moisture level, acidity, and other factors critical to maintaining life. This is called **homeostasis,** or the maintenance of internal conditions within certain boundaries.

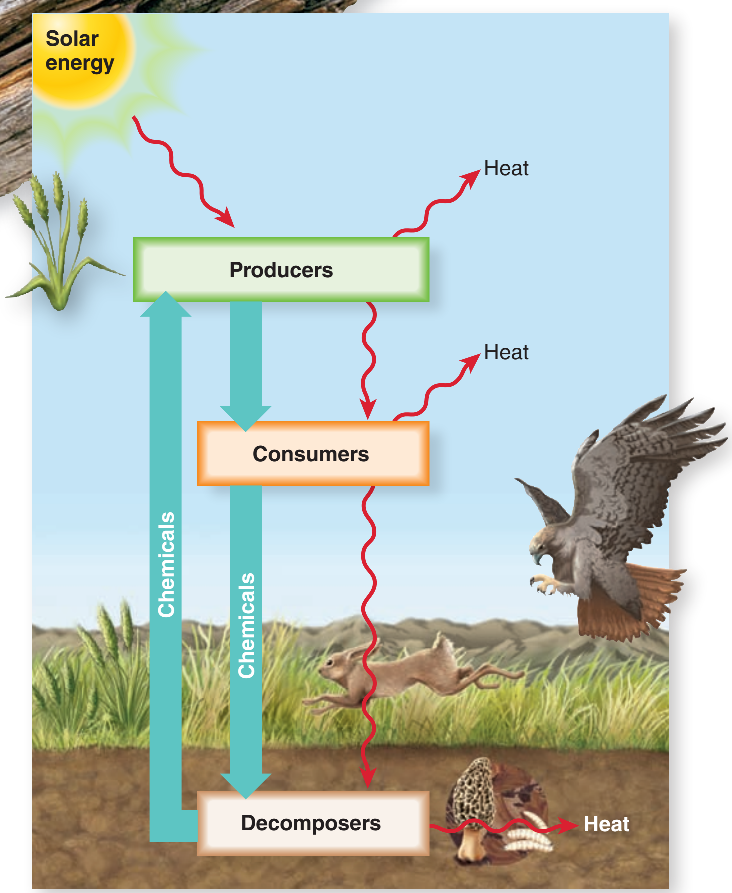

Figure 1.4 **Chemical cycling and energy flow in an ecosystem.**

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.

Many organisms depend on behavior to regulate their internal environment. A chilly lizard may raise its internal temperature by basking in the sun on a hot rock. When it starts to overheat, it scurries for cool shade. Other organisms have control mechanisms that do not require any conscious activity. When you are studying and forget to eat lunch, your liver releases stored sugar to keep your blood sugar level within normal limits. Many of the organ systems of our bodies are involved in maintaining homeostasis.

Living Organisms Respond

Living organisms find energy and/or nutrients by interacting with their surroundings. Even single-celled organisms can respond to their environment. The beating of microscopic hairs or the snapping of whiplike tails moves them toward or away from light or chemicals. Multicellular organisms can manage more complex responses. A monarch butterfly can sense the approach of fall and begin its flight south, where resources are still abundant. A vulture can smell meat a mile away and soar toward dinner.

The ability to respond often results in movement: The leaves of a plant turn toward the sun, and animals dart toward safety. Appropriate responses help ensure survival of the organism and allow it to carry on its daily activities. Altogether, we call these activities the *behavior* of the organism.

Living Organisms Reproduce and Develop

Life comes only from life. Every type of living thing can **reproduce,** or make another organism like itself. Bacteria and other types of single-celled organisms simply split in two. In multicellular organisms, the reproductive process usually 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 individual, which grows and develops through various stages to become an adult.

An embryo develops into a whale or a yellow daffodil or a human because of the specific set of **genes,** or genetic instructions, inherited from its parents (**Fig. 1.5**). In all organisms, the genes are made of long DNA (deoxyribonucleic acid) molecules, but even so the genes are different between species and individuals. 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. Advances in DNA technology allow for the rapid screening of the variation in our genes. These genetic comparisons are the basis of paternity testing. Although an individual's overall genetic makeup is unique, it consists of DNA from both parents. Thus, the DNA profiles of a child and his or her biological parents are measurably similar.

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 ones are turned on in each type of specialized cell. Genetic testing can look for the presence of certain mutations and, in doing so, can help us predict what diseases we are prone to, and doctors can use this information to prescribe drug therapy or tell us how best to protect ourselves.

Figure 1.5 **A human family.**

Whether they are single-celled or multicellular, all organisms reproduce. Offspring receive a copy of their parents' DNA and therefore a copy of their genes.

Living Organisms Have Adaptations

Adaptations are modifications that make organisms suited to their way of life. Some hawks have the ability to catch fish (see Fig. 1.3); others are best at catching rabbits. Hawks can fly, in part, because they have hollow bones to reduce their weight and flight muscles to depress and elevate their wings. When a hawk dives, its strong feet take the first shock of the landing, and its long, sharp claws reach out and hold on to the prey. Hawks have exceptionally keen vision, which enables them not only to spot prey from great heights but also to estimate distance and speed.

Video
Harris Hawk

Penguins look very different from hawks, although they are both birds. Penguins are adapted to an aquatic existence in the Antarctic. While birds such as hawks have forelimbs proportioned for flying, penguins have stubby, flattened wings suitable for swimming. Their feet and tails serve as rudders in the water, but their flat feet also allow them to walk on land. Penguins live where it is cold; an extra layer of downy feathers is covered by short, thick feathers to form a waterproof coat. Layers of blubber also keep the birds warm in cold water.

Evolution, or the manner in which species become adapted to their environment, is discussed in the next section of this chapter.

1.1 CONNECTING THE CONCEPTS
All living organisms share the same basic feature.

Check Your Progress 1.1

1. List the basic characteristics common to all life.
2. List, in order starting with the least organized, the levels of biological organization.
3. Explain how chemical cycling and energy flow occur at both the organism and the ecosystem levels of organization.

1.2 Evolution: The Core Concept of Biology

Learning Outcomes

Upon completion of this section, you should be able to

1. Define the term *evolution*.
2. Explain the process of natural selection and its relationship to evolutionary processes.
3. Summarize the general characteristics of the domains and major kingdoms 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 living organisms suggests that they are descended from a common ancestor—the first cell or cells.

An evolutionary tree is like a family tree (**Fig. 1.6**). 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. 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. **Evolution** is the process in which populations accumulate adaptations over time to become more suited to their environments. Evolution may be considered the unifying concept of biology because it explains so many aspects of biology, including how living organisms arose from a single ancestor and the tremendous diversity of life on the planet.

Natural Selection and Evolutionary Processes

In the nineteenth century, two naturalists—Charles Darwin and Alfred Russell Wallace—came to the conclusion independently that evolution occurs by means of a process called **natural selection.** Charles Darwin is the more famous of the two because he wrote a book called *On the Origin of Species,* which presented much data to substantiate the occurrence of evolution by natural selection. Since that time, evolution has become the core concept of biology because the theory explains so many different types of observations in every field of biology.

The process of natural selection is based on how a population changes in response to its environment. Environments may change due to the influence of living factors (such as a new predator) or nonliving factors (such as temperature). As the environment changes over time, some individuals of a species may possess certain adaptations that make them better suited to the new 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

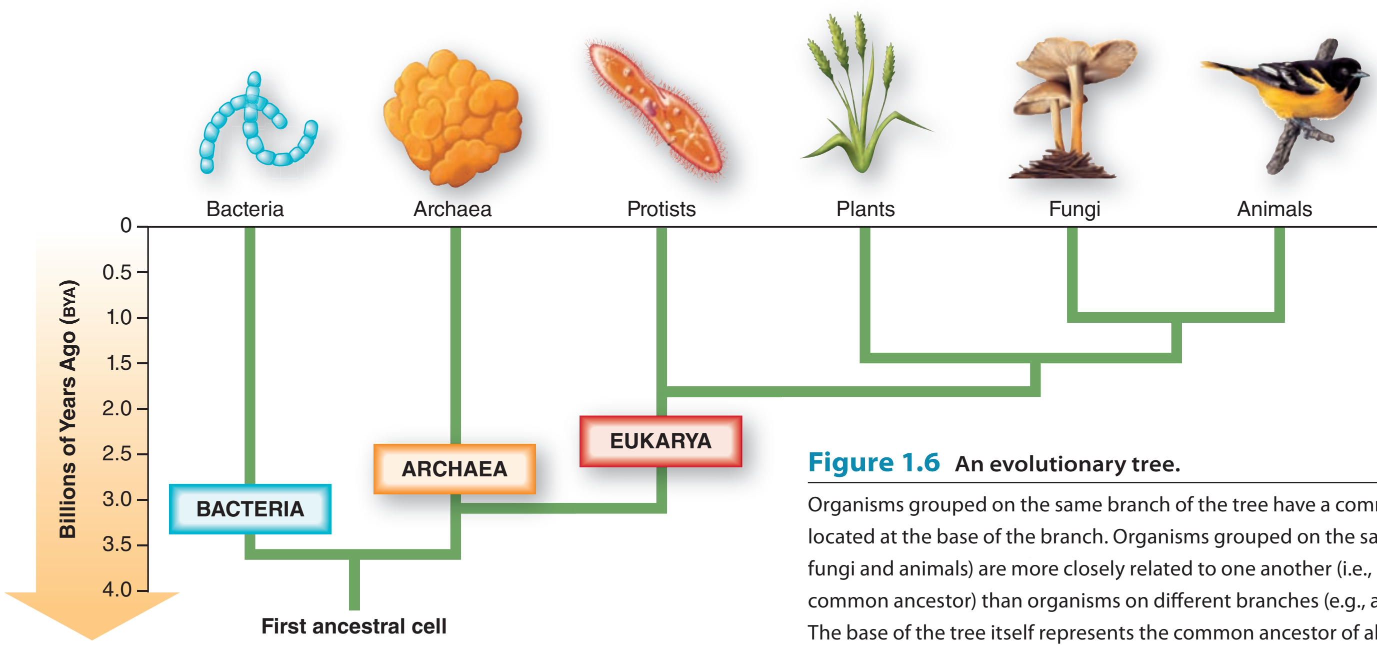

Figure 1.6 An evolutionary tree.

Organisms grouped on the same branch of the tree have a common ancestor located at the base of the branch. Organisms grouped on the same branch (e.g., fungi and animals) are more closely related to one another (i.e., have a more recent common ancestor) than organisms on different branches (e.g., animals and plants). The base of the tree itself represents the common ancestor of all living organisms.

selection, results in changes in the characteristics of a population over 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 is called evolution.

The phrase "common descent with modification" sums up the process of evolution because it means that, as descent occurs from common ancestors, modifications occur that cause these organisms to be adapted (suited) to the environment. As a result, one species can be a common ancestor to several species, each adapted to a particular set of environmental conditions. Specific adaptations allow species to play particular roles in their environment. The Hawaiian honeycreepers are a remarkable example of this process (**Fig. 1.7**). The 50+ species of honeycreepers all evolved from one species of finch, which likely originated in North America and arrived in the Hawaiian islands between 3 and 5 million years ago. Modern honeycreepers have an assortment of bill shapes adapted to different types of food. Some honeycreeper species have curved, elongated bills used for drinking flower nectar. Others have strong, hooked bills suited to digging in tree bark and seizing wood-boring insects or have short, straight, finchlike bills for feeding on small seeds and fruits. Even with such dramatic differences in feeding habits and bill shapes, honeycreepers still share certain characteristics, which stem from their common finch ancestor. The various honeycreeper species are similar in body shape and size, as well as mating and nesting behavior.

The study of evolution encompasses all levels of biological organization. Indeed, much of today's evolution research is carried out at the molecular level, comparing the DNA of different groups of organisms to determine how they are related. Looking at how life has changed over time, from its origin to the current day, helps us understand why there are so many different kinds of organisms and why they have the characteristics they do. An understanding of evolution by natural selection also has practical applications, including the prevention and treatment of disease.

Today we know that, because of selection, resistance to antibiotic drugs has become increasingly common in a number of bacterial species, including those that cause tuberculosis, gonorrhea, and staph infections. Antibiotic drugs, such as penicillin, kill susceptible bacteria. However, some bacteria in the body of a patient undergoing antibiotic treatment may be unharmed by the drug. Bacteria can survive antibiotic drugs in many different ways. For example, certain bacteria can endure treatment with penicillin because they break down the drug, rendering it harmless. If even one bacterial cell lives because it is antibiotic-resistant, then its descendants will inherit this drug-defeating ability. The more antibiotic drugs are used, the more natural selection favors resistant bacteria, and the more often antibiotic-resistant infections will occur.

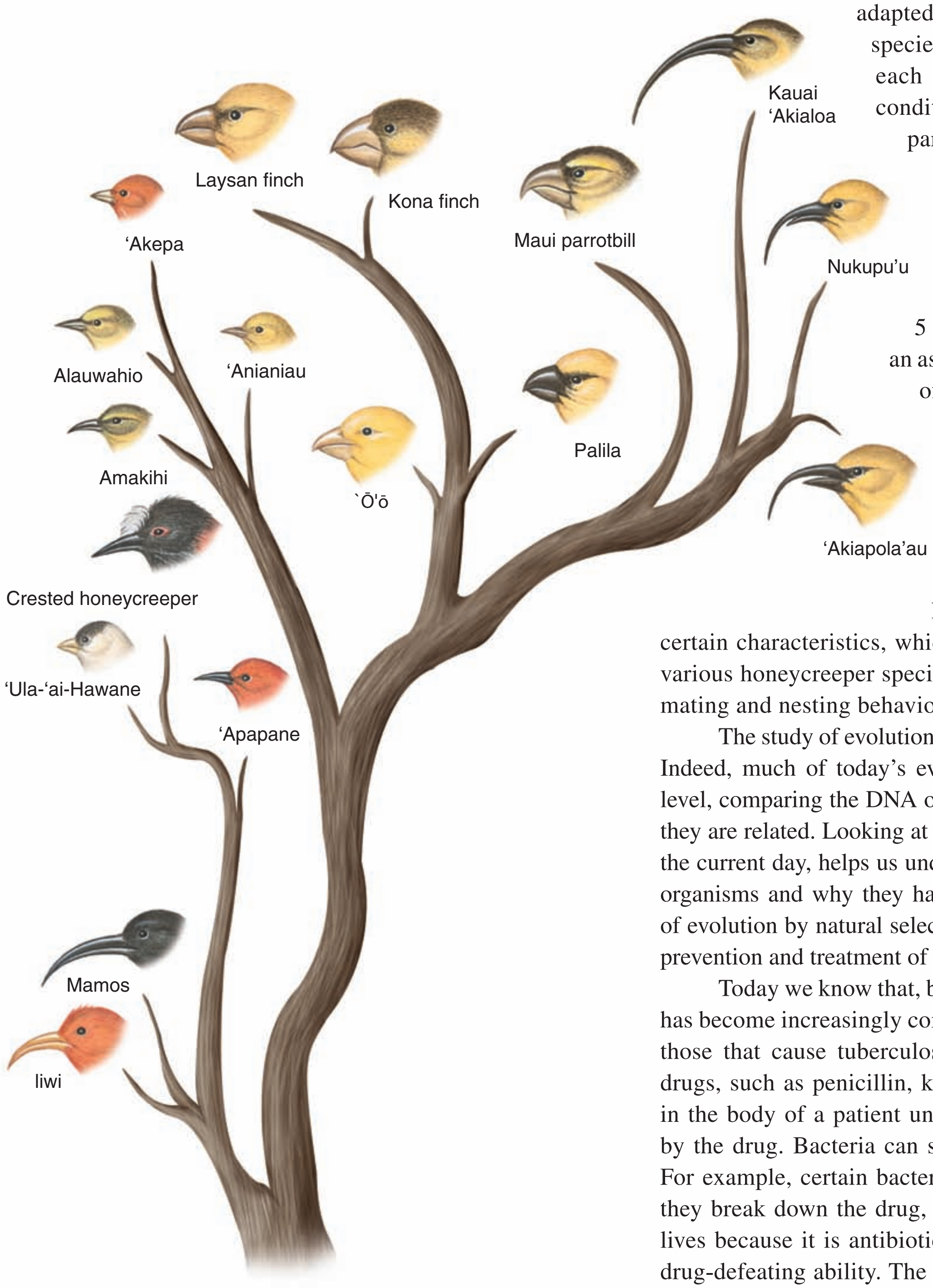

Figure 1.7 **Evolution of Hawaiian honeycreepers.**

Hawaiian honeycreepers, descendants of a single ancestral species, display an amazing diversity of bill shapes and sizes.

Connections: Health

How does evolution affect me personally?

In the presence of an antibiotic, resistant bacteria are selected to reproduce over and over again, until the entire population of bacteria becomes resistant to the antibiotic. In 1959, a new antibiotic called methicillin became available to treat bacterial (staph) infections that were already resistant to penicillin. In 1974, 2% of the staph infections were classified as MRSA (methicillin-resistant *Staphylococcus aureus*), but by 2004, the number had risen to 63%. In response, the Centers for Disease Control and Prevention conducted an aggressive campaign to educate health-care workers on MRSA prevention. The program was very successful, and between 2005 and 2008 the number of MRSA infections in hospitals declined by 28%. However, MRSA resistance remains an important concern of the medical community.

Organizing the Diversity of Life

Think of an enormous department store, offering thousands of different items for sale. The various items are grouped in departments—electronics, apparel, furniture, and so on—to make them easy for customers to find. Because life is so diverse, it is helpful to have a system that groups organisms into categories. Two areas of biology help us group organisms into categories: **Taxonomy** is the discipline of identifying and naming organisms according to certain rules, and **systematics** makes sense out of the bewildering variety of life on Earth by classifying organisms according to their presumed evolutionary relationships. As systematicists learn more about evolutionary relationships between species, the taxonomy of a given organism may change. Systematicists are even now making observations and performing experiments that will one day bring about changes in the classification system adopted by this text.

Categories of Classification

The classification categories, from least inclusive to most inclusive, are **species, genus, family, order, class, phylum, kingdom,** and **domain** (**Table 1.1**). Each successive 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 domain share only general characteristics. 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 with trees. By the same token, only modern humans are in the genus *Homo,* but many types of species, from tiny hydras to huge whales, are members of the animal kingdom. Species placed in different domains are the most distantly related. For now, we will focus on the general characteristics of the domains and kingdoms of life.

Table 1.1 Levels of Biological Organization

Category	Human	Corn
Domain	Eukarya	Eukarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Anthophyta
Class	Mammalia	Liliopsida
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.*