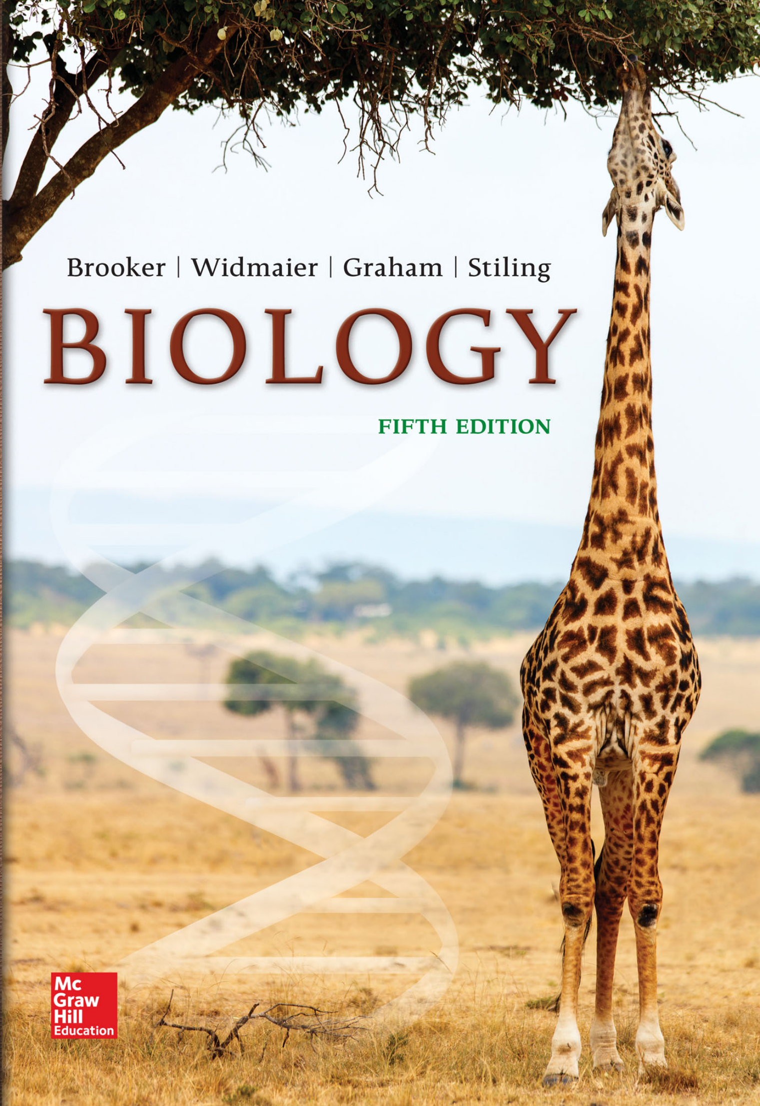

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BIOLOGY

FIFTH EDITION

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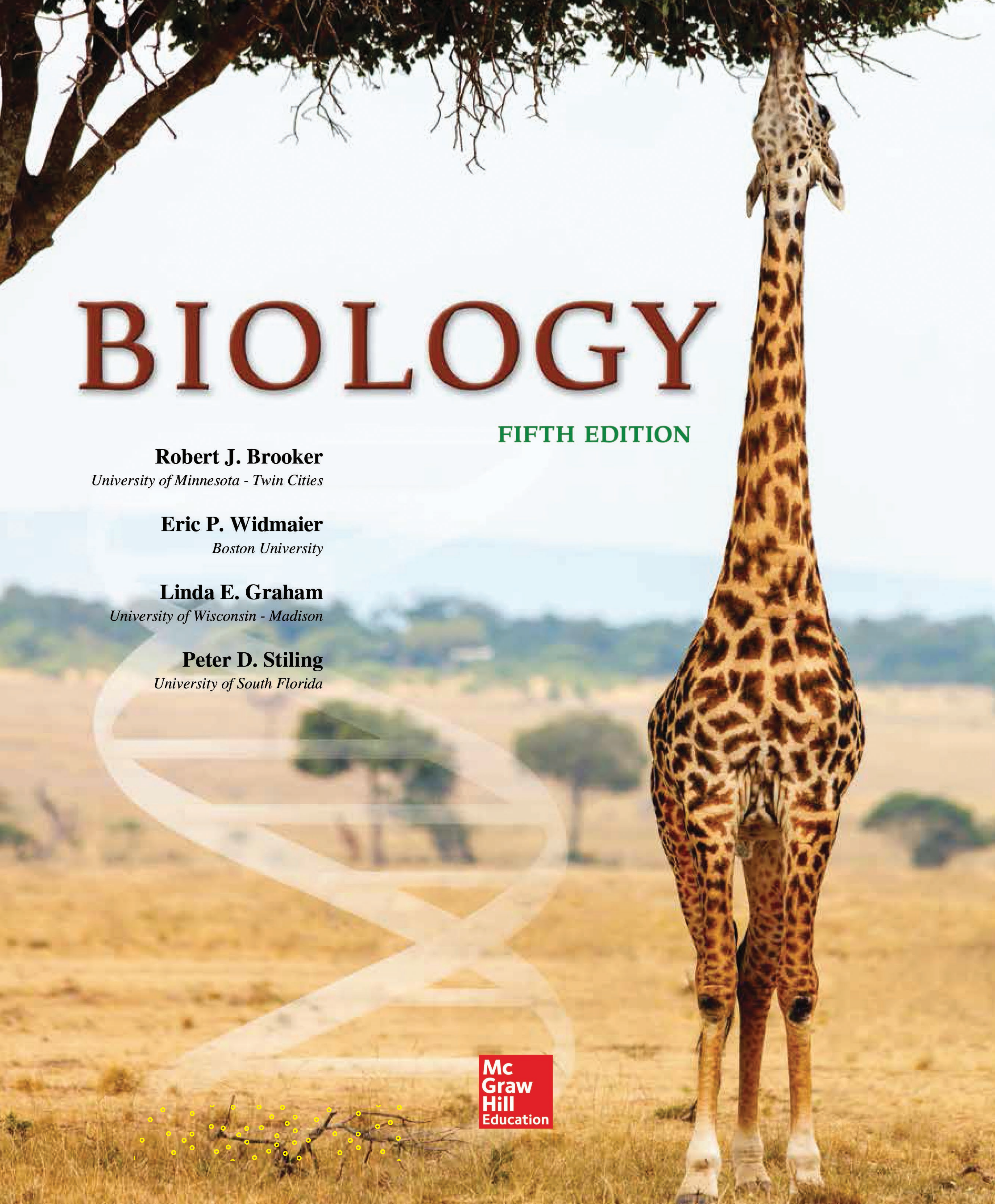

BIOLOGY

FIFTH EDITION

Robert J. Brooker
University of Minnesota - Twin Cities

Eric P. Widmaier
Boston University

Linda E. Graham
University of Wisconsin - Madison

Peter D. Stiling
University of South Florida

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BIOLOGY, FIFTH EDITION

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Brief Contents

About the Authors

Robert J. Brooker

Rob Brooker (Ph.D., Yale University) received his B.A. in biology at Wittenberg University, Springfield, Ohio, in 1978, and studied genetics while a graduate student at Yale. For his postdoctoral work at Harvard, he studied lactose permease, the product of the *lacY* gene of the *lac* operon. He continued working on transporters at the University of Minnesota, where he is a Professor in the Department of Genetics, Cell Biology, and Development and the Department of Biology Teaching and Learning. At the University of Minnesota, Dr. Brooker teaches undergraduate courses in biology, genetics, and cell biology. In addition to many other publications, he has written two undergraduate genetics texts published by McGraw-Hill: *Genetics: Analysis & Principles*, 6th edition, copyright 2018, and *Concepts of Genetics*, 3rd edition, copyright 2019.

Eric P. Widmaier

Eric Widmaier received his B.A. degree in biological sciences at Northwestern University in 1979, where he performed research in animal behavior. In 1984, he earned his Ph.D. in endocrinology from the University of California at San Francisco, where he examined hormonal actions and their mechanisms in mammals. As a postdoctoral fellow at the Worcester Foundation for Experimental Research and later at The Salk Institute, he continued his focus on the cellular and molecular control of hormone secretion and action, with a particular focus on the brain. His current research focuses on the control of body mass and metabolism in mammals, the hormonal correlates of obesity, and the effects of high-fat diets on intestinal cell function. Dr. Widmaier is currently Professor of Biology at Boston University, where he teaches undergraduate human physiology and recently received the university's highest honor for excellence in teaching. Among other publications, he is lead author of *Vander's Human Physiology: The Mechanisms of Body Function*, 15th edition, published by McGraw-Hill, copyright 2019.

Linda E. Graham

Linda Graham earned an undergraduate degree from Washington University (St. Louis), a master's degree from the University of Texas, and Ph.D. from the University of Michigan, Ann Arbor, where she also did postdoctoral research. Presently Professor of Botany at the University of Wisconsin-Madison, her research explores the evolutionary origins of algae and land-adapted plants, focusing on their cell and molecular biology as well as microbial interactions. In recent years Dr. Graham has engaged in research expeditions to remote regions of the world to study algal and plant microbiomes. She teaches undergraduate courses in microbiology and plant biology. She is the coauthor of, among other publications, *Algae*, 3rd edition, copyright 2016, a textbook on algal biology, and *Plant Biology*, 3rd edition, copyright 2015, both published by LJLM Press.

Left to right: Eric Widmaier, Linda Graham, Peter Stiling, and Rob Brooker

The authors are grateful for the help, support, and patience of their families, friends, and students, Deb, Dan, Nate, and Sarah Brooker, Maria, Caroline, and Richard Widmaier, Jim, Michael, Shannon, and Melissa Graham, and Jacqui, Zoe, Leah, and Jenna Stiling.

Peter D. Stiling

Peter Stiling obtained his Ph.D. from University College, Cardiff, United Kingdom. Subsequently, he became a postdoctoral fellow at Florida State University and later spent two years as a lecturer at the University of the West Indies, Trinidad. Dr. Stiling was formerly Chair of the Department of Integrative Biology at the University of South Florida (USF) at Tampa, where he is currently an Assistant Vice Provost for Strategic Initiatives and Professor of Biology. His research interests include plant-animal relationships and invasive species. He currently teaches biology to students in the USF in London summer program which he established in 2015. Dr. Stiling was elected an AAAS Fellow in 2012. He is also the author of *Ecology: Global Insights and Investigations*, 2nd edition, published by McGraw-Hill.

A Message from the Authors

As active teachers and writers, one of the great joys of this process for us is that we have been able to meet many more educators and students during the creation of this textbook. It is humbling to see the level of dedication our peers bring to their teaching. Likewise, it is encouraging to see the energy and enthusiasm so many students bring to their studies. We hope this book and its digital resources will serve to aid both faculty and students in meeting the challenges of this dynamic and exciting course. For us, this remains a work in progress, and we encourage you to let us know what you think of our efforts and what we can do to serve you better.

Rob Brooker, Eric Widmaier, Linda Graham, Peter Stiling

Acknowledgements

The lives of most science-textbook authors do not revolve around an analysis of writing techniques. Instead, we are people who understand science and are inspired by it, and we want to communicate that information to our students. Simply put, we need a lot of help to get it right.

Editors are a key component who help the authors modify the content of this textbook so it is logical, easy to read, and inspiring. The editorial team for this *Biology* textbook has been a catalyst that kept this project rolling. The members played various roles in the editorial process. Andrew Urban and his predecessor Justin Wyatt, Portfolio Managers (Majors Biology), have done an excellent job overseeing the 5th edition. Elizabeth Sievers, Senior Product Developer, has been the master organizer. Liz's success at keeping us on schedule is greatly appreciated. We would also like to acknowledge our copy editor, Jane Hoover, for her thoughtful editing that has contributed to the clarity of this textbook.

Another important aspect of the editorial process is the actual design, presentation, and layout of materials. It's confusing if the text and art aren't on the same page, or if a figure is too large or too small. We are indebted to the tireless efforts of Jessica Portz, Content Project Manager, and David Hash, Senior Designer at McGraw-Hill. Likewise, our production company, MPS Limited, did an excellent job with the paging, revision of existing art, and the creation of new art for the 5th edition. Their artistic talents, ability to size and arrange figures, and attention to the consistency of the figures have been remarkable. We would also like to acknowledge the ongoing efforts of the superb marketing staff at McGraw-Hill. Special thanks to Kelly Brown, Executive Marketing Manager, whose effort intensifies when this edition comes out.

Finally, other staff members at McGraw-Hill Higher Education have ensured that the authors and editors were provided with adequate resources to achieve the goal of producing a superior textbook. These include G. Scott Virkler, Senior Vice President, Products & Markets; Michael Ryan, Vice President, General Manager, Products & Markets; and Betsy Whalen, Vice President, Production and Technology Services.

Reviewers for *Biology*, 5th edition

- Lubna Abu-Niaaj *Central State University*
- Joseph Covi *University of North Carolina at Wilmington*
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- Kimberly Wallace *Texas A & M University San Antonio*
- Megan Wise de Valdez *Texas A & M University San Antonio*

A Modern Vision for Learning: Emphasizing Core Concepts and Core Skills

Over the course of five editions, the ways in which biology is taught have dramatically changed. We have seen a shift away from the memorization of details, which are easily forgotten, and a movement toward emphasizing core concepts and critical thinking skills. The previous edition of *Biology* strengthened skill development by adding two new features, called CoreSKILLS and BioTIPS (described later), which are aimed at helping students develop effective strategies for solving problems and applying their knowledge in novel situations. In this edition, we have focused our pedagogy on the five core concepts of biology as advocated by "Vision and Change" and introduced at a national conference organized by the American Association for the Advancement of Science (see www.visionandchange.org). These core concepts, which are introduced in Chapter 1 (see Figure 1.4) include the following:

1. ***Evolution:*** The diversity of life evolved over time by processes of mutation, selection, and genetic exchange.
2. ***Structure and function:*** Basic units of structure define the function of all living things.
3. ***Information flow, exchange, and storage:*** The growth and behavior of organisms are activated through the expression of genetic information.
4. ***Pathways and transformations of energy and matter:*** Biological systems grow and change via processes that are based on chemical transformation pathways and are governed by the laws of thermodynamics.
5. ***Systems:*** Living systems are interconnected and interacting.

In addition to core concepts, "Vision and Change" has strongly advocated the development of core skills (also called core competencies). Those skills that are emphasized in this textbook are as follows:

- The ability to apply the process of science
- The ability to use quantitative reasoning
- The ability to use models and simulation (each chapter in *Biology, 5e*, contains a new feature called Modeling Challenge that asks students to create their own model or interpret a model provided)
- The ability to tap into the interdisciplinary nature of science
- The ability to communicate and collaborate with professionals in other disciplines
- The ability to understand the relationship between science and society

A key goal of this textbook is to bring to life these five core concepts of biology and the core skills. These concepts and skills are highlighted in each chapter with a "Vision and Change" icon, , which indicates subsections and figures that focus on one or more of them. This approach will serve two purposes. First, the icon will help students to see how the various topics in this textbook are connected to each other by the five core concepts of biology. Second, the icon will allow students to appreciate the important skills they are developing as they progress through the text.

KEY PEDAGOGICAL FEATURES OF THIS EDITION

The author team is dedicated to producing the most engaging and current text available for undergraduate students who are majoring in biology. We have listened to educators and reviewed documents, such as *Vision and Change, A Call to Action*, which includes a summary of recommendations made at a national conference organized by the American Association for the Advancement of Science. We want our textbook to reflect core concepts and skills and provide a more learner-centered approach. To achieve these goals, *Biology*, 5th edition, has the following pedagogical features.

- *NEW!* **Core Concepts:** As mentioned, the five core concepts are introduced in Chapter 1 (see Figure 1.4). Throughout Chapters 2 through 60, these core concepts are emphasized by a Vision and Change icon, , placed next to headings of particular subsections and beneath certain figure legends.

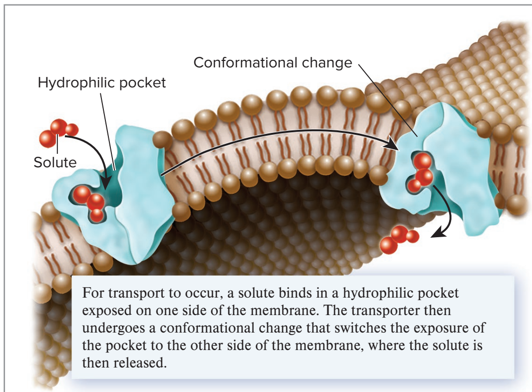


Figure 5.17 Mechanism of transport by a transporter, also called a carrier.

Core Concept: Structure and Function Two structural features—a hydrophilic pocket and the ability to switch back and forth between two conformations—allow transporters to move ions and molecules across the membrane.

- ***NEW!*** **Core Skills:** Six core skills are also introduced in Chapter 1 (see Section 1.6). In Chapters 2 through 60, these core skills are emphasized by a Vision and Change icon, , placed next to headings of particular subsections, such as Feature Investigations, and beneath certain figure legends. To distinguish them from the **Core Concepts,** the **Core Skills** are highlighted in blue type. In addition, the designator **CoreSKILLS** has been added to certain learning outcomes and end-of-chapter questions that emphasize skills needed in the study of biology.

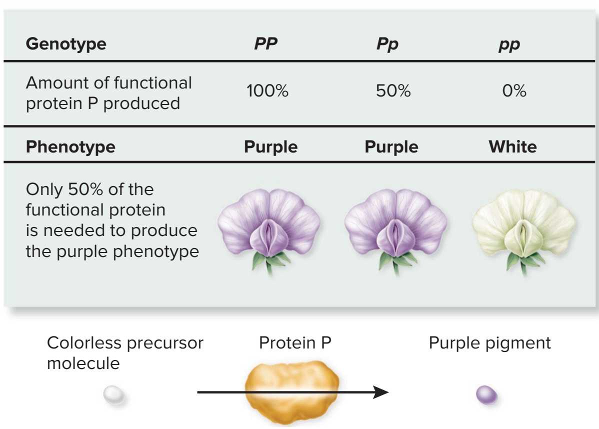


Figure 17.16 How genes give rise to traits during simple Mendelian inheritance. In the heterozygote, the amount of protein encoded by a single dominant allele is sufficient to produce the dominant phenotype. In this example, the gene encodes an enzyme that is needed to produce a purple pigment. A plant with one or two copies of the dominant allele makes enough pigment to produce purple flowers. In a *pp* homozygote, the complete lack of the functional protein (enzyme) results in white flowers.

Core Skill: Quantitative Reasoning In a simple dominant/recessive relationship, even though the heterozygote may produce less of a functional protein compared to the homozygote that has two copies of the dominant allele, the amount made by the heterozygote is sufficient to yield the dominant phenotype.

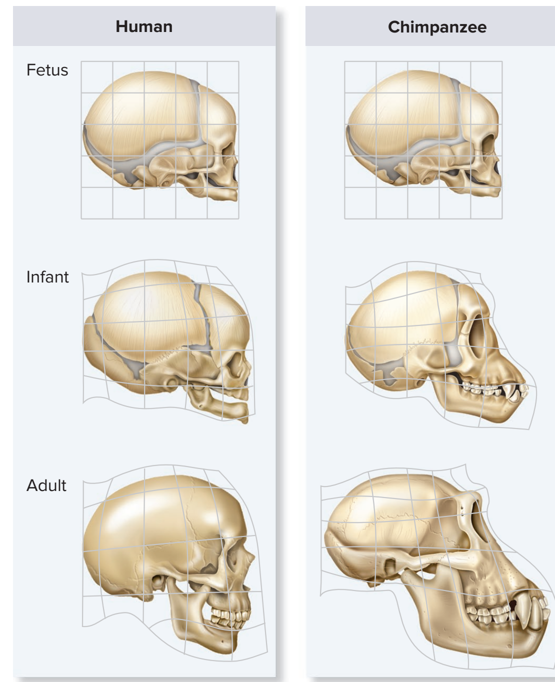


Figure 24.16 Heterochrony. Due to heterochrony, one region of the body may grow faster than another during development in different species. For example, the skulls of adult chimpanzees and humans have different shapes even though their fetal skull shapes are quite similar.

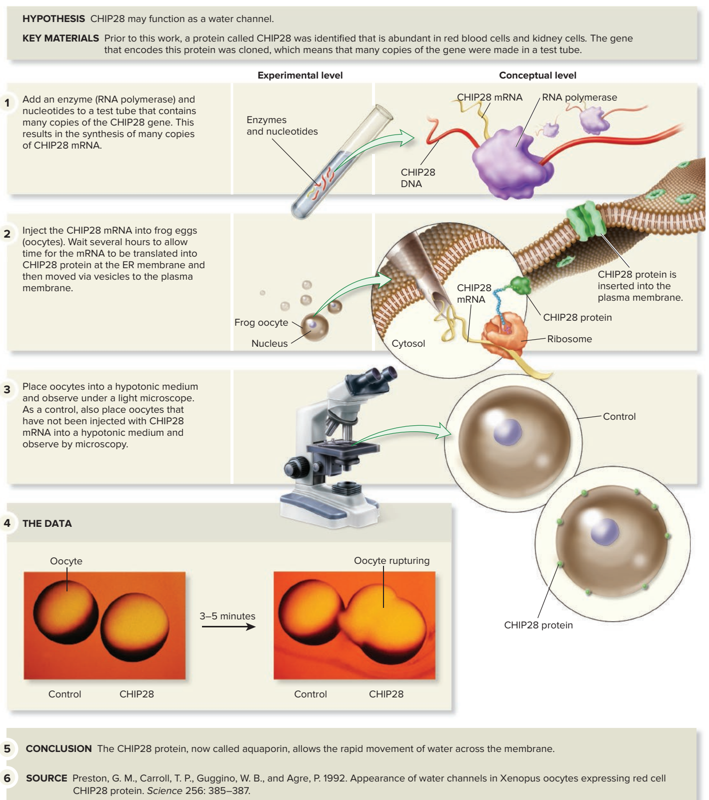
Core Skill: Modeling The goal of this modeling challenge is to make a series of models that show the differences in limb lengths among orangutans, chimpanzees, and humans.

Modeling Challenge: Search the Internet and look at photos of orangutans, chimpanzees, and humans. Even though these species look similar, one noticeable difference is the relative lengths of their limbs. Although the limbs in an early fetus look similar in all three species, the limbs in the adults show significant differences in their relative lengths. Draw models, similar to those in **Figure 24.16**, that show an early fetus, infant, and adult for all three species. Include an explanation of how heterochrony affects limb development.

- ***NEW!*** **Modeling Challenges:** A growing trend is the use of models in biology education. Students are asked to interpret models and to create models based on data or a scenario. Furthermore, using models and simulations is one of the core skills that is emphasized by "Vision and Change." The author team has added a new feature called **Modeling Challenge** that asks students to create a model or to interpret a model they are given. Possible answers to the **Modeling Challenges** are provided in Connect.

- **Feature Investigations:** The emphasis on skill development continues in the Feature Investigations, which provide complete descriptions of experiments. These investigations begin with background information in the text that describes the events that led to a particular study. The study is then presented as an illustration that begins with the hypothesis and then describes the experimental protocol at the experimental and conceptual levels. The illustration also includes data and the conclusions that were drawn from the data. This integrated approach helps students to understand how experimentation leads to an understanding of biological concepts.

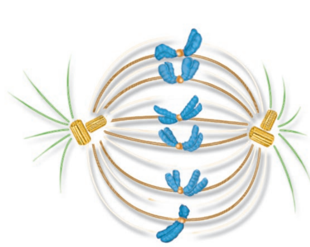
Figure 5.16 **The discovery of water channels (aquaporins) by Agre.** (4): Courtesy Dr. Peter Agre



- **BioTIPS:** A feature that was added to the previous edition is aimed at helping students improve their problem-solving skills. Chapters 2 through 60 contain solved problems called **BioTIPS**, where "TIPS" stands for **T**opic, **I**nformation, and **P**roblem-Solving **S**trategy. These solved problems follow a consistent pattern in which students are given advice on how to solve problems in biology using 11 different problem-solving strategies: Make a drawing. Compare and contrast. Relate structure and function. Sort out the steps in a complicated process. Propose a hypothesis. Design an experiment. Predict the outcome. Interpret data. Use statistics. Make a calculation. Search the literature.

BIO TIPS

THE QUESTION *A diploid cell has 12 chromosomes, or 6 pairs. In the following diagram, in what phase of mitosis, meiosis I or meiosis II, is this cell?*



T OPIC ***What topic in biology does this question address?*** The topic is cell division. More specifically, the question is asking you to be able to look at a drawing and discern which phase of cell division a particular cell is in.

I NFORMATION ***What information do you know based on the question and your understanding of the topic?*** In the question, you are given a diagram of a cell at a particular phase of the cell cycle. This cell is derived from a mother cell with 6 pairs of chromosomes. From your understanding of the topic, you may remember the various phases of mitosis, meiosis I, and meiosis II, which are described in Figures 16.8 and 16.13. If so, you may initially realize that the cell is in metaphase.

P ROBLEM-SOLVING S TRATEGY ***Sort out the steps in a complicated process.*** To solve this problem, you may need to describe the steps, starting with a mother cell that has 6 pairs of chromosomes. Keep in mind that a mother cell with 6 pairs of chromosomes has 12 chromosomes during G_1, which then replicate to form 12 pairs of sister chromatids during S phase. Therefore, at the beginning of M phase, this mother cell will have 12 pairs of sister chromatids. During mitosis, the 12 pairs of sister chromatids will align at metaphase. During meiosis I, 6 bivalents will align along the metaphase plate in the mother cell. During meiosis II, 6 pairs of sister chromatids will align along the metaphase plate in the two cells.

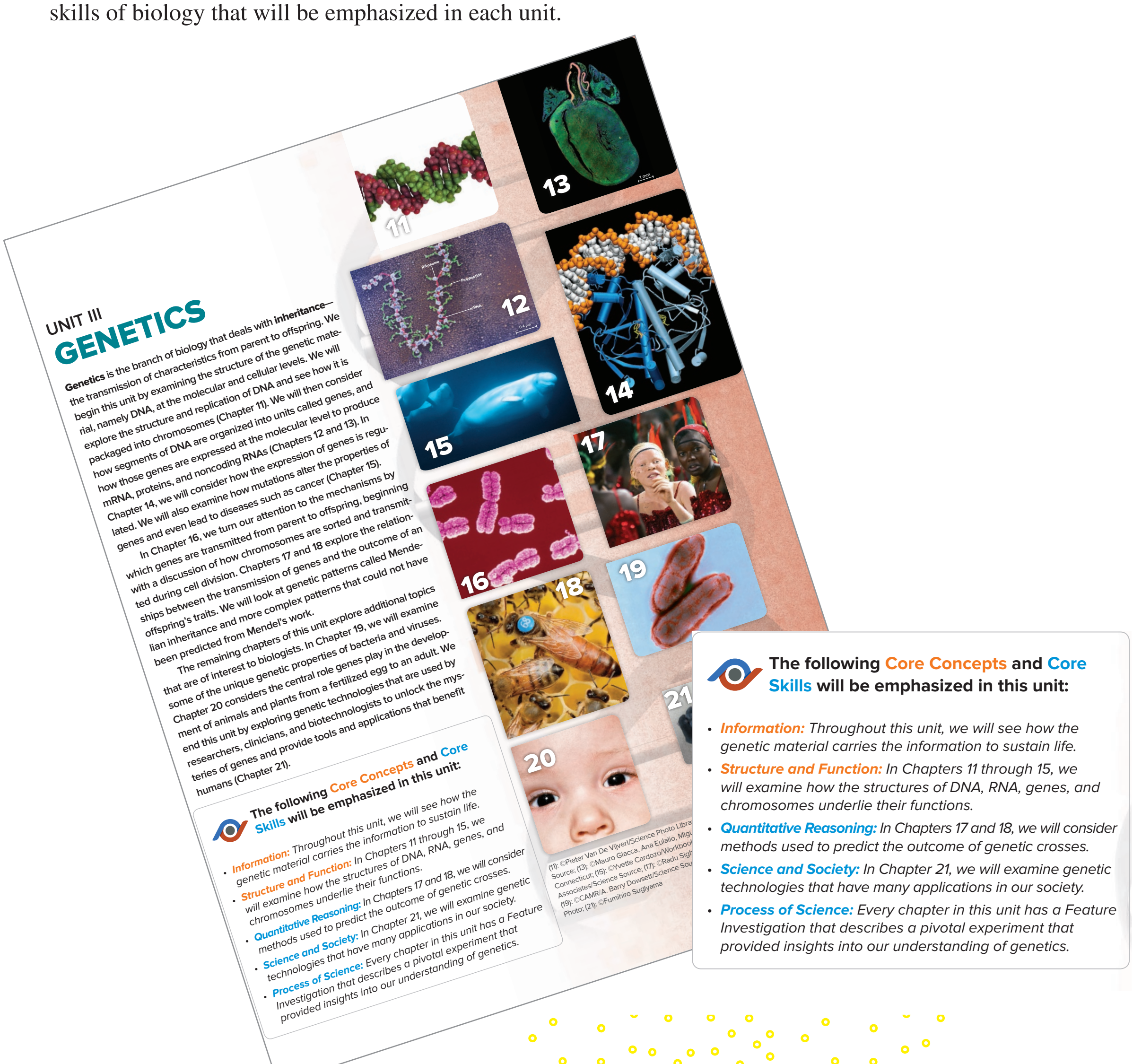
ANSWER *The cell is in metaphase of meiosis II. You can tell because the chromosomes are lined up in a single row along the metaphase plate, and the cell has only 6 pairs of sister chromatids. If it were mitosis, the cell would have 12 pairs of sister chromatids. If it were in meiosis I, bivalents would be aligned along the metaphase plate.*

- **Formative Assessment:** A trend in biology education is to spend more class time engaging students in active learning. While this is a positive approach that fosters learning, a drawback is that instructors have less time to explain the material in the textbook. When students are expected to learn textbook material on their own, it is imperative that they are regularly given formative assessment—feedback regarding their state of learning while they are engaging in the learning process. This allows students to gauge whether they are mastering the material. Formative assessment is a major feature of this textbook and is bolstered by Connect—a state-of-the art digital assignment and assessment platform. In *Biology*, 5th edition, formative assessment is provided in multiple ways.
  - First, many figure legends have Concept Check questions that focus on key concepts of a given topic.
  - Second, questions in Assess and Discuss at the end of each chapter explore students' understanding of concepts and mastery of skills. Core Concepts and Core Skills are again addressed under the Conceptual Questions. The answers to the Concept Checks and the end-of-chapter questions are in Appendix B, so students can immediately see if they are mastering the material.

Conceptual Questions

1. The Earth's atmosphere consists of 78% nitrogen. Why is nitrogen a limiting nutrient?
2. Why does maximum sustainable yield occur at the midpoint of the logistic curve and not where the population is at carrying capacity?
3. **Core Skill: Science and Society** In one family, parents, who were born in 1900, have twins at age 20 but then have no more children. Their children, grandchildren, and so on behave in the same way. In another family, parents, who were also born in 1900, delay reproduction until age 33 but have triplets. Their children and grandchildren behave in the same way. Which family has the most descendants by 2000? What can you conclude?

- In Connect, a particularly robust type of formative assessment is SmartBook, which guides a student through the textbook. SmartBook is an adaptive learning tool that is described later in this Preface.
- **Unit openers:** Each unit begins with a unit opener that provides an overview of the chapters within that unit. This overview allows the student to see the big picture of the unit. In addition, the unit openers draw attention to the core concepts and core skills of biology that will be emphasized in each unit.



- **Learning Outcomes:** As advocated in *Vision and Change*, educational materials should have well-defined learning goals. Each section of every chapter begins with a set of Learning Outcomes. These outcomes inform students of the key concepts they will learn and the skills they will acquire in mastering the material. They also provide a tangible indication of how student learning will be assessed. The assessments in Connect were developed using these Learning Outcomes as a guide in formulating online questions, thereby linking the learning goals of the text with the assessments in Connect.

13.1 Overview of Non-coding RNAs

Learning Outcomes:

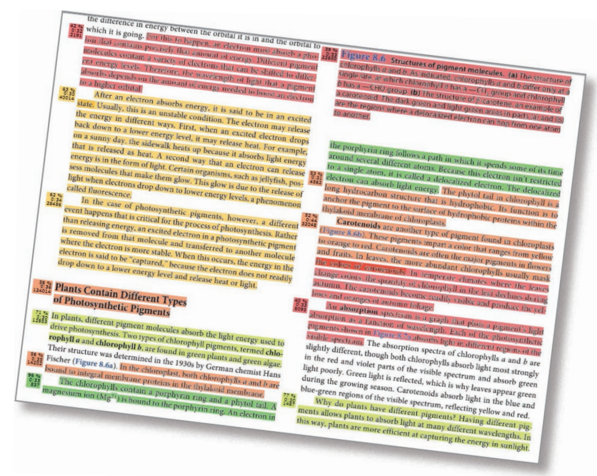
1. Describe the ability of ncRNAs to bind to other molecules and macromolecules.
2. Outline the general functions of ncRNAs.
3. Define ribozyme.
4. List several examples of ncRNAs, and describe their functions.

USING STUDENT USAGE DATA TO MAKE IMPROVEMENTS

To help guide the revision for the 5th edition, the authors consulted student usage data and input, which were derived from thousands of SmartBook® users of the 4th edition. SmartBook "heat maps" provided a quick visual snapshot of chapter usage data and the relative difficulty students experienced in mastering the content. These data directed the authors to evaluate text content that was particularly challenging for students. These same data were also used to revise the SmartBook probes.

- If the data indicated that the subject was more difficult than other parts of the chapter, as evidenced by a high proportion of students responding incorrectly to the SmartBook questions, the authors revised or reorganized the content to be as clear and illustrative as possible, for example, by rewriting the section or providing additional examples or revised figures to assist visual learners.
- In other cases, one or more of the SmartBook questions for a section was not as clear as it should have been or did not appropriately reflect the content in the chapter. In these cases the question, rather than the text, was edited.

Below is an example of one of the heat maps from Chapter 8. The color-coding of highlighted sections indicates the various levels of difficulty students experienced in learning the material, topics highlighted in red being the most challenging for students.


the difference in energy between the orbital it is in and the orbital to which it is going. For this to happen, an electron must absorb a photon that contains precisely that amount of energy. Different pigment molecules contain a variety of electrons that can be shifted to different energy levels. Therefore, the wavelength of light that a pigment absorbs depends on the amount of energy needed to boost an electron to a higher orbital.

After an electron absorbs energy, it is said to be in an excited state. Usually, this is an unstable condition. The electron may release the energy in different ways. First, when an excited electron drops back down to a lower energy level, it may release heat. For example, on a sunny day, the sidewalk heats up because it absorbs light energy that is released as heat. A second way that an electron can release energy is in the form of light. Certain organisms, such as jellyfish, possess molecules that make them glow. This glow is due to the release of light when electrons drop down to lower energy levels, a phenomenon called fluorescence.

In the case of photosynthetic pigments, however, a different event happens that is critical for the process of photosynthesis. Rather than releasing energy, an excited electron in a photosynthetic pigment is removed from that molecule and transferred to another molecule where the electron is more stable. When this occurs, the energy in the electron is said to be "captured," because the electron does not readily drop down to a lower energy level and release heat or light.

Plants Contain Different Types of Photosynthetic Pigments

In plants, different pigment molecules absorb the light energy used to drive photosynthesis. Two types of chlorophyll pigments, termed **chlorophyll *a*** and **chlorophyll *b***, are found in green plants and green algae. Their structure was determined in the 1930s by German chemist Hans Fischer (Figure 8.6a). In the chloroplast, both chlorophylls *a* and *b* are bound to integral membrane proteins in the thylakoid membrane.

The chlorophylls contain a porphyrin ring and a phytol tail. A magnesium ion (Mg^{2+}) is bound to the porphyrin ring. An electron in the porphyrin ring follows a path in which it spends some of its time around several different atoms. Because this electron isn't restricted to a single atom, it is called a delocalized electron. The delocalized electron can absorb light energy. The phytol tail in chlorophyll is a long hydrocarbon structure that is hydrophobic. Its function is to anchor the pigment to the surface of hydrophobic proteins within the thylakoid membrane of chloroplasts.

Carotenoids are another type of pigment found in chloroplasts (Figure 8.6b). These pigments impart a color that ranges from yellow to orange to red. Carotenoids are often the major pigments in flowers and fruits. In leaves, the more abundant chlorophylls usually mask the colors of carotenoids. In temperate climates where the leaves change colors, the quantity of chlorophyll in the leaf declines during autumn. The carotenoids become readily visible and produce the yellows and oranges of autumn foliage.

An **absorption** spectrum is a graph that plots a pigment's light absorption as a function of wavelength. Each of the photosynthetic pigments shown in Figure 8.7a absorbs light in different regions of the visible spectrum. The absorption spectra of chlorophylls *a* and *b* are slightly different, though both chlorophylls absorb light most strongly in the red and violet parts of the visible spectrum and absorb green light poorly. Green light is reflected, which is why leaves appear green during the growing season. Carotenoids absorb light in the blue and blue-green regions of the visible spectrum, reflecting yellow and red.

Why do plants have different pigments? Having different pigments allows plants to absorb light at many different wavelengths. In this way, plants are more efficient at capturing the energy in sunlight.

Figure 8.6 Structures of pigment molecules. (a) The structure of chlorophylls *a* and *b*. As indicated, chlorophylls *a* and *b* differ only at a single site, at which chlorophyll *a* has a $—CH_3$ group and chlorophyll *b* has a —CHO group. (b) The structure of β-carotene, an example of a carotenoid. The dark green and light green areas in parts (a) and (b) are the regions where a delocalized electron can hop from one atom to another.

Preparing Students for Careers in Biololgy with *NEW* Cutting-Edge Content

A key purpose of a majors biology course is to prepare students for biology-related careers, including those in the health professions, teaching, and research. The author team has reflected on the direction of biology and how that direction will affect future careers that students may pursue. We are excited to announce that *Biology,* 5th edition, has four new chapters that reflect current trends in biology research and education. These trends are opening the doors to exciting new career options in biology.

- ***Chapter 13. Gene Expression at the Molecular Level II: Non-coding RNAs.*** The past decade or so has seen an explosion in the discovery of different types of non-coding RNAs. This work has revealed a variety of roles of non-coding RNAs at the molecular level, as well as roles in human diseases and plant health.
- ***Chapter 30. Microbiomes: Microbial Systems On and Around Us.*** Recent research has revealed the staggering complexity and biological importance of microbiomes—assemblages of microbes that are associated with a particular host or environment. This new chapter explores how microbiomes are analyzed and describes their interactions with diverse hosts, including humans, protists, and plants.
- ***Chapter 53: Integrated Responses of Animal Organ Systems to a Challenge to Homeostasis.*** Systems biology has been a recent trend in biological research and education. This chapter takes systems biology to a new level by exploring how multiple organs systems respond in a coordinated way to the same threat—a challenge to homeostasis.
- ***Chapter 59: The Age of Humans.*** We face a tug-of-war between the undesirable effects of humans on the environment and the efforts of ecologists to prevent such changes. This new chapter surveys the impacts that the growing human population has had on climate change and on the survival of native species. This material may inspire some students to pursue a career as an ecologist or environmental biologist.

With regard to the scientific content in the textbook, the author team has worked with faculty reviewers to refine this new edition and to update the content so that students are exposed to the most current material. In addition to the four new chapters and our new pedagogical additions involving **Core Concepts, Core Skills,** and **Modeling Challenges,** every chapter has been extensively edited for clarity, presentation, layout, readability, modifications of artwork, and new and challenging end-of-chapter questions. Examples of some of the key changes are summarized below.

- **Chapter 1. An Introduction to Biology.** Chapter 1 provides a description of the **Core Concepts** (see Figure 1.4) and the **Core Skills** (see Section 1.6) that are advocated by *Vision and Change*.

Chemistry Unit

- **Chapter 2. The Chemical Basis of Life I: Atoms, Molecules, and Water.** The topics of pH and buffers have been placed in their own section (see Section 2.4).

Cell Unit

- **Chapter 4. Evolutionary Origin of Cells and Their General Features.** This chapter now begins with a discussion of the evolutionary origin of cells (see Section 4.1). It also discusses a new topic, droplet organelles, which are organelles that are not surrounded by a membrane (see Section 4.3).
- **Chapter 6. An Introduction to Energy, Enzymes, and Metabolism.** For the topic of how cells use ATP as a source of energy, a revised subsection compares the **Core Concept: Information** to the **Core Concept: Energy and Matter.**
- **Chapter 7. Cellular Respiration and Fermentation.** A **Modeling Challenge** asks students to predict the effects of a mutation on the function of ATP synthase (see Figure 7.12).
- **Chapter 10. Multicellularity.** Four figures have been revised to better depict the relative locations of cell junctions between animal cells.

Genetics Unit

- **Chapter 11. Nucleic Acid Structure, DNA Replication, and Chromosome Structure.** Figure 11.8b has a **Modeling Challenge** that asks students to predict how the methylation of a base would affect the ability of that base to hydrogen bond with a base in the opposite strand.
- **Chapter 13. *NEW!* Gene Expression at the Molecular Level II: Non-coding RNAs.** This new chapter begins with an overview of the general properties of non-coding RNAs and then describes specific examples in which non-coding RNAs are involved with chromatin structure, transcription, translation, protein sorting, and genome defense.
- **Chapter 16. The Eukaryotic Cell Cycle, Mitosis, and Meiosis.** The **Core Concept: Evolution** is highlighted in a subsection that explains how mitosis in eukaryotes evolved from binary fission in prokaryotic cells (see Figure 16.10).
- **Chapter 17. Mendelian Patterns of Inheritance.** The organization of this chapter has been revised to contain the patterns of inheritance that obey Mendel's laws.
- **Chapter 18. Epigenetics, Linkage, and Extranuclear Inheritance.** This chapter now covers inheritance patterns that violate Mendel's laws. The topic of epigenetics has been expanded from one section in the previous edition to four sections in the 5th edition (see Sections 18.1 through 18.4).
- **Chapter 19. Genetics of Viruses and Bacteria.** Discussion of the Zika virus has been added to this chapter.
- **Chapter 21. Genetic Technologies and Genomics.** The use of CRISPR-Cas technology to alter genes is now discussed (see Figure 21.10).

Evolution Unit

- **Chapter 22. An Introduction to Evolution.** This chapter has been moved so that it is the first chapter in this unit on evolution.
- **Chapter 23. Population Genetics.** After learning about the Hardy-Weinberg equation, students are presented with a **Modeling Challenge** that asks them to propose a mathematical model that extends the Hardy-Weinberg equation to a gene that exists in three alleles (see Figure 23.2).
- **Chapter 25. Taxonomy and Systematics.** The topic of taxonomy is related to the **Core Concept: Evolution** through an explanation of how taxonomy is based on the evolutionary relationships among different species.
- **Chapter 26. History of Life on Earth and Human Evolution.** The topic of human evolution has been moved from the unit on diversity to this unit. The expanded version of this topic describes recent examples of human evolution and discusses the amount of genetic variation between different human populations (see Section 26.3).

Diversity Unit

- **Chapter 27. Archaea and Bacteria.** This chapter has been reorganized to provide essential background for new Chapter 30 (an exploration of microbiomes). The **Core Skill: Connections** is illustrated by linking electromagnetic sensing in bacteria with that in certain animals.
- **Chapter 29. Fungi.** An overview of fungal phylogeny has been updated to reflect new research discoveries. Coverage of plant root-fungal associations (mycorrhizae) and lichens has been moved to new Chapter 30.
- **Chapter 30. *NEW!* Microbiomes: Microbial Systems On and Around Us.** This new chapter integrates information about microbial diversity (Chapters 27 through 29) with material on genetic technologies that is introduced in Chapter 21 to explain the evolutionary, medical, agricultural, and environmental importance of microbial associations.
- **Chapter 31. Plants and the Conquest of Land.** The diagrammatic overview of plant phylogeny has been updated to reveal challenges in understanding the pattern of plant evolution.
- **Chapter 33. An Introduction to Animal Diversity.** Figure 33.3, animal phylogeny, has been redrawn to reflect the idea that ctenophores, rather than sponges, are now considered to be the earliest diverging animals. Section 33.2 on animal classification has been largely revised.
- **Chapter 34. The Invertebrates.** Following the new themes introduced in Chapter 33, this chapter has been reorganized to discuss ctenophores as the earlier evolving animals, followed by sponges, cnidria, jellyfish, and other radially symmetrical animals.

Flowering Plants Unit

- **Chapter 36. An Introduction to Flowering Plant Form and Function.** A new chapter opener links the economic importance of plants, represented by cotton, to the significance of plant structure-function relationships.

- **Chapter 37. Flowering Plants: Behavior.** A **Modeling Challenge** links plant responses to conditions on Earth to those experienced in space.
- **Chapter 38. Flowering Plants: Nutrition.** In a **Modeling Challenge** related to plant-microbe interaction process, students infer how specific mutations might affect an important nutritional feature.
- **Chapter 40. Flowering Plants: Reproduction.** This chapter explores intriguing parallels between the reproductive processes of animals and those of plants.

Animals Unit

- **Chapter 41. Animal Bodies and Homeostasis.** A section entitled "Homeostatic Control of Internal Fluids" (Section 41.4) now follows the section "General Principles of Homeostasis," providing students with an understanding of body fluid compartments, osmolarity, and how animal bodies exchange ions and water with their environments. These concepts are important to students' understanding of subsequent chapters.
- **Chapter 42. Neuroscience I: Cells of the Nervous System.** The **Core Skill: Science and Society** is featured numerous times in the unit on animals, including in Figure 42.18 which describes the use of magnetic resonance imaging in modern medicine.
- **Chapter 43. Neuroscience II: Evolution, Structure, and Function of the Nervous System.** The **Core Skill: Connections** is also featured throughout the unit on animals, including in Figure 43.1 in which students are asked to identify the defining features of animals by referring to Chapter 33.
- **Chapter 44. Neuroscience III: Sensory Systems.** New research demonstrating a correlation between the types of locomotion of vertebrates and the relative sizes of their semicircular canals is described.
- **Chapter 46. Nutrition and Animal Digestive Systems.** A **Modeling Challenge** was added in which students are tasked with creating models of hypothetical alimentary canals of two species with different diets, eating patterns, and teeth.
- **Chapter 47. Control of Energy Balance, Metabolic Rate, and Body Temperature.** The meaning of body mass index and its usefulness and limitations are more fully elucidated, and data on obesity statistics in the United States have been updated to reflect current trends.
- **Chapter 48. Circulatory and Respiratory Systems.** These topics were formerly addressed in two chapters but are now integrated into a single chapter that streamlines the presentation and emphasizes important connections between the two systems.
- **Chapter 49. Excretory Systems.** The chapter has been more narrowly focused on excretory systems by moving the material on osmoregulation and body fluids earlier in the unit, to Chapter 41.
- **Chapter 51. Animal Reproduction and Development.** Formerly two chapters, this material is now covered in one chapter, which eliminated redundancy in coverage. For example, the topic of fertilization (Section 51.2) is now covered in its entirety in the same section as the topic of gametogenesis, rather than being split between two chapters.
- **Chapter 52. Immune Systems.** Exciting new information has been added that describes the evolution of toll-like receptors and the presence of a TLR-domain in bacterial genes associated with immune defenses.
- **Chapter 53. *NEW!* Integrated Responses of Animal Organ Systems to a Challenge to Homeostasis.** This new chapter integrates material from virtually the entire unit on animals, using a classic challenge to homeostasis as an example. It includes a compelling case study of a young athlete that begins and concludes the chapter.

Ecology Unit

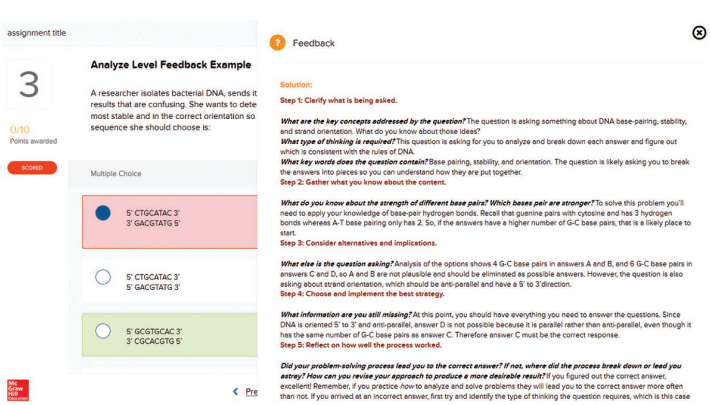
- **Chapter 54. An Introduction to Ecology and Biomes.** The section on aquatic biomes as been expanded with a new figure and explanation of the annual cycle of temperate lakes, as well as new information on tide formation and waves.
- **Chapter 57. Species Interactions.** This chapter has been reduced in length by the deletion of four figures and streamlined for easier understanding.
- **Chapter 58. Communities and Ecosystems: Ecological Organization at Large Scales.** This chapter has been reorganized to include both community ecology and ecosystems ecology.
- **Chapter 59. *NEW!* The Age of Humans.** This new chapter synthesizes information concerning the effects of humans on the natural environment. It contains discussions of human population growth (previously covered in Chapter 56), the effect of global warming on climate change (previously covered in Chapter 54), and human effects on biogeochemical cycles and biomagnification (previously covered in Chapter 59), and new information on habitat destruction, overexploitation, and invasive species.
- **Chapter 60. Biodiversity and Conservation Biology.** The coverage of the value of biodiversity to human welfare, detailed in Section 60.3 has been updated and expanded.

Detailed Feedback in Connect®

Learning is a process of iterative development, of making mistakes, reflecting, and adjusting over time. The question and test banks in Connect® for *Biology*, 5th edition, are more than direct assessments; they are self-contained learning experiences that systematically build student learning over time.

For many students, choosing the right answer is not necessarily based on applying content correctly; it is more a matter of increasing the statistical odds of guessing. A major fault with this approach is students don't learn how to process the questions correctly, mostly because they are repeating and reinforcing their mistakes rather than reflecting and learning from them. To help students develop problem-solving skills, all higher-level Bloom's questions in Connect are supported with hints, to help students focus on important information needed to answer the questions, and detailed feedback that walks students through the problem-solving process, using Socratic questions in a decision-tree framework to scaffold learning, in which each step models and reinforces the learning process.

The feedback for each higher-level Bloom's question (Apply, Analyze, Evaluate) follows a similar process: Clarify Question, Gather Content, Consider Alternatives, Choose Answer, Reflect on Process.

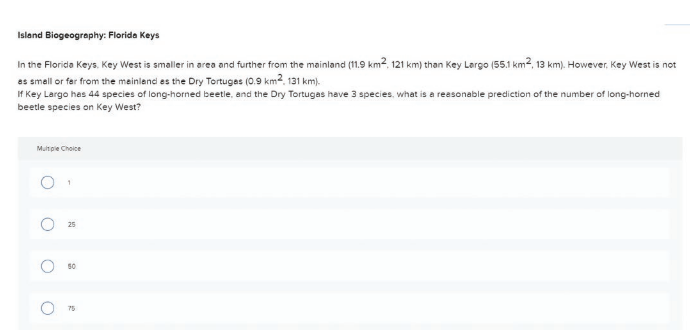


Unpacking the Concepts

We've taken problem solving a step further. In each chapter, two higher-level Bloom's questions in the question and test banks are broken down according to the steps in the detailed feedback. Rather than leaving it up to the student to work through the detailed feedback, we present a second version of the question in a stepwise format. Following the problem-solving steps, students need to answer questions about the problem-solving process, such as "What is the key concept addressed by the question?" before answering the original question. A professor can choose which version of the question to include in the assignment based on the problem-solving skills of the students.

Graphing Interactives

To help students develop analytical skills, Connect® for *Biology*, 5th edition, is enhanced with interactive graphing questions. Students are presented with a scientific problem and the opportunity to manipulate variables, producing different results on a graph. A series of questions follows the graphing activity to assess if the student understands and is able to interpret the data and results.



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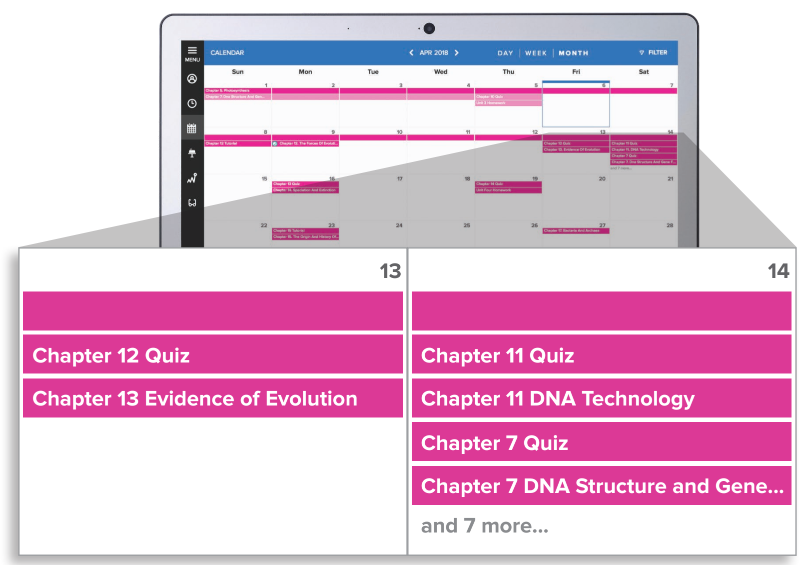

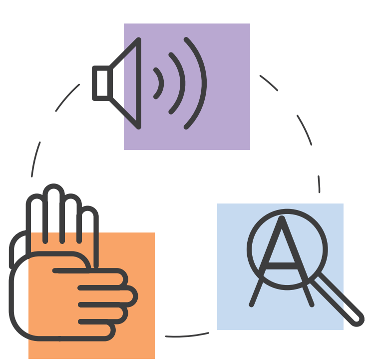

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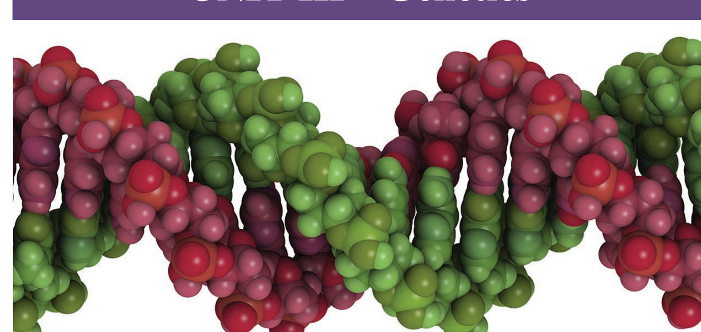

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CHAPTER OUTLINE

1 An Introduction to Biology

The giraffe, genus *Giraffa*. Giraffes, which are found in Africa, are the tallest living terrestrial animals. They are members of the genus *Giraffa*. Until recently, biologists thought that all giraffes belonged to a single species. As discussed later in this chapter, that view may be changing as a result of analyses of genetic features of giraffes from different regions of Africa. ©Robert Muckley/Getty Images

Biology is the study of life. The diverse forms of life found on Earth provide biologists with an amazing array of organisms to study. In many cases, the investigation of living things leads to discoveries that no one would have imagined. For example, researchers determined that the venom from certain poisonous snakes contains a chemical that lowers blood pressure in humans. By analyzing that chemical, scientists developed drugs to treat high blood pressure (**Figure 1.1**).

Biologists have discovered that plants can communicate with each other. For example, the beautiful umbrella thorn acacia (*Vachellia tortillis*), shown in **Figure 1.2**, emits volatile organic molecules when it is attacked by herbivores. These molecules warn other nearby acacia trees that herbivores are in the area, and those trees release toxins to protect themselves.

Another interesting example of a biological discovery is a seemingly bizarre phenomenon known as **zombie parasites**. As you may know, zombies are fictional creatures featured in some horror and fantasy novels and movies, where they appear as dead

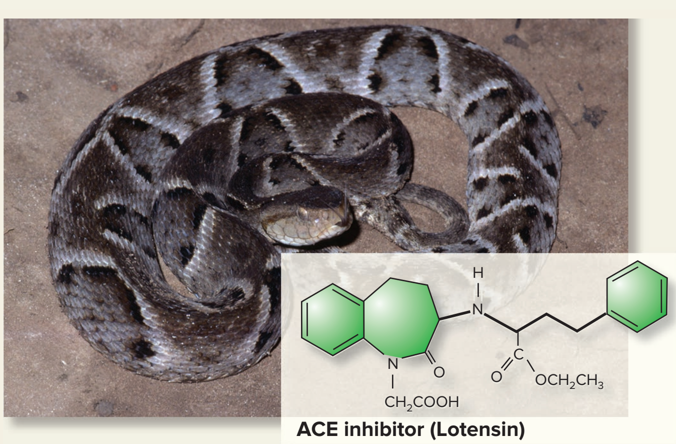


Figure 1.1 The Brazilian arrowhead viper and an inhibitor of high blood pressure. Derivatives of a chemical, called an angiotensin-converting enzyme (ACE) inhibitor, are found in the venom of the Brazilian arrowhead viper and are commonly used to treat high blood pressure. ©Francois Gohier/Science Source

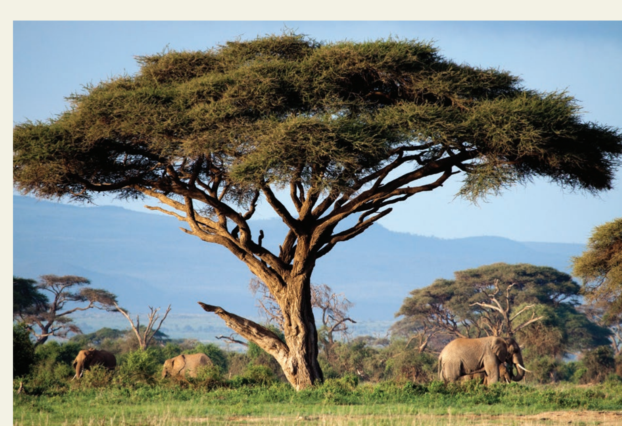


Figure 1.2 Plant communication. If attacked by herbivores, this acacia tree will emit molecules that will warn other acacia trees in the area. ©Mark Snodgrass/Getty Images

Table 1.1	Examples of Zombie Parasites	
Host	**Parasite**	**Description**
House cricket (*Acheta domesticus*)	Horsehair worm (*Paragordius varius*)	A horsehair worm larva infects a cricket and grows inside it. The cricket is terrestrial, but the adult stage of the horsehair worm is aquatic. When the larva matures into an adult, it alters the behavior of the cricket, causing it to jump into the nearest body of water! As the cricket drowns, an adult horsehair worm emerges.
Spider (*Plesiometa argyra*)	Wasp (*Hymenoepimecis argyraphaga*)	A female wasp glues an egg onto a spider's body. After the egg develops into a larva, the larva pokes a few holes in the spider's abdomen, which allows it to suck the spider's blood and also to transfer chemicals into the spider, which control its behavior. The spider stops building its normal orb-shaped web and starts building a web whose geometry is strikingly different: The new web is designed to suspend the larva's cocoon in the air, where it will be protected from predators.
Various vertebrates, including mice and rats	Protozoan (*Toxoplasma gondii*)	*Toxoplasma gondii* is a parasite whose life cycle involves more than one vertebrate host. The definitive host is the cat, which is where *T. gondii* becomes mature and reproduces sexually. An intermediate host can be any of a variety of vertebrates, including mice and rats, which can ingest the parasite from cat feces. In the intermediate host, the parasite develops and reproduces asexually. To escape an intermediate host, such as a mouse or rat, and move to the definitive host, *T. gondii* dramatically alters the host's behavior. The infected animal becomes attracted to the smell of cat urine! This makes it more likely to be eaten by a cat and thereby allows *T. gondii* to enter its definitive host and mature.

creatures that are able to move because of some magical force. A zombie parasite is a parasite that infects its host and is then able to control the host's behavior. A relatively small group of researchers have begun to investigate this phenomenon, and their work has spawned a new field called **neuroparasitology**—the study of how parasites control the nervous systems of their hosts. During the past few decades, researchers have discovered many examples of zombie parasites. A few are described in **Table 1.1**.

These are but a few of the many discoveries that make biology an intriguing discipline. The study of life not only reveals the fascinating characteristics of living species but also leads to the development of medicines and research tools that benefit the lives of people.

To make new discoveries, biologists view life from many different perspectives: What is the composition of living things? How is life organized? How do organisms reproduce? Sometimes the questions posed by biologists are fundamental and even philosophical in nature: How did living organisms originate? Can we live forever? What is the physical basis for memory? Can we save endangered species?

Future biologists will continue to make important advances. Biologists are scientific explorers looking for answers to some of life's most enduring mysteries. Unraveling these mysteries presents exciting challenges to the best and brightest minds. The rewards of a career in biology include the excitement of forging into uncharted territory, the thrill of making discoveries that can improve the health and lives of people, and the satisfaction of trying to preserve the environment and protect endangered species. For these and many other compelling reasons, students seeking challenging and rewarding careers may wish to choose biology as a lifelong pursuit.

In this chapter, we will begin by examining the levels of biology and the core concepts that are common to all forms of life. One of those core concepts is evolution, which is discussed in greater depth in Section 1.3. We then explore the general approaches that scientists follow when making new discoveries. Finally, we will consider the skills that students need to develop as they pursue careers in this exciting discipline and the ways in which this textbook fosters those skills.

1.1 Levels of Biology

Learning Outcome:

1. Explain how life can be viewed at different levels of biological complexity.

Let's begin our journey through the wonderful world of biology by considering how life is organized. The term **organism** can be applied to all forms of life. Organisms maintain an internal order that is separated from the environment. The complexity of living organisms can be analyzed at different levels, starting with the smallest level of organization and progressing to levels that are physically much larger and more complex. **Figure 1.3** depicts a biologist's view of the levels of biological organization.

1. ***Atoms.*** An **atom** is the smallest unit of an element that has the chemical properties of the element. All matter is composed of atoms.
2. ***Molecules and macromolecules.*** As discussed in Unit I, atoms bond with each other to form **molecules**. A polymer such as a polypeptide is formed of many molecules bonded together and is called a **macromolecule**. Carbohydrates, proteins, and nucleic acids (DNA and RNA) are important macromolecules found in living organisms.
3. ***Cells.*** The simplest unit of life is the **cell**, which we will examine in Unit II. A cell is surrounded by a membrane and contains a variety of molecules and macromolecules. Unicellular organisms are composed of one cell, whereas multicellular organisms, such as plants and animals, contain many cells.
4. ***Tissues.*** In multicellular organisms, many cells of the same type associate with each other to form **tissues**. An example is muscle tissue.
5. ***Organs.*** In complex multicellular organisms, an **organ** is composed of two or more types of tissue. For example, the heart is composed of several types of tissues, including muscle, nervous, and connective tissue.

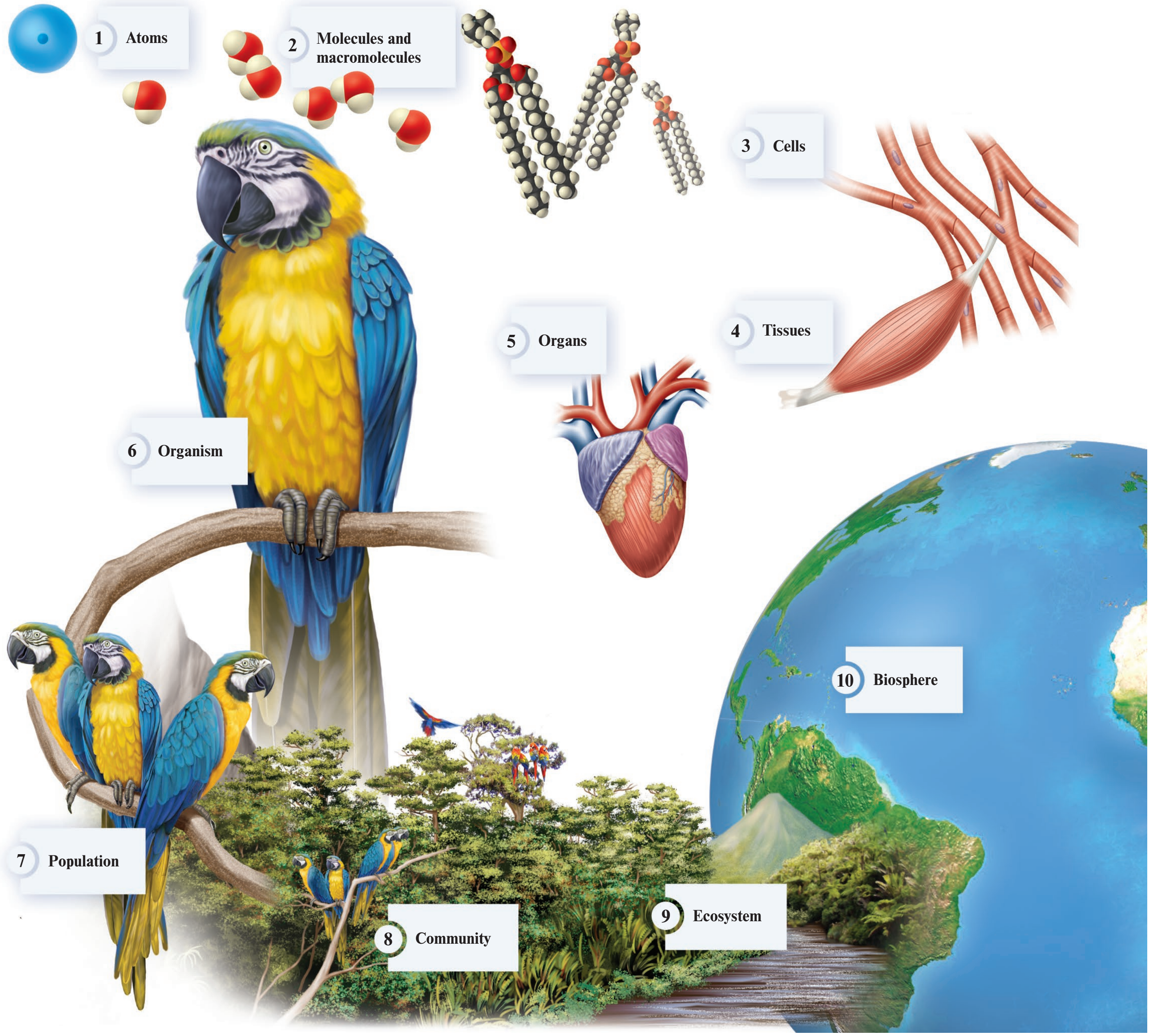


Figure 1.3 **The levels of biological organization.**

Concept Check: *At which level of biological organization would you place a herd of buffalo?*

6. ***Organism.*** All living things can be called **organisms**. Biologists classify organisms as belonging to a particular **species**, which is a related group of organisms that share a distinctive form and set of attributes in nature. The members of the same species are closely related genetically. In Units VI and VII, we will examine plants and animals at the level of cells, tissues, organs, and complete organisms.
7. ***Population.*** A group of organisms of the same species that occupy the same environment is called a **population**.
8. ***Community.*** A biological **community** is an assemblage of populations of different species. The types of species found in a community are determined by the environment and by the interactions of species with each other.
9. ***Ecosystem.*** Researchers may extend their work beyond living organisms and also study the physical environment. Ecologists analyze **ecosystems**, which are formed by interactions of a community of organisms with their physical environment. Unit VIII considers biological organization from populations to ecosystems.
10. ***Biosphere.*** The **biosphere** includes all of the places on the Earth where living organisms exist. Life is found in the air, in bodies of water, on the land, and in the soil.

1.2 Core Concepts of Biology

Learning Outcome:

1. Describe the core concepts of biology as advocated by "Vision and Change."

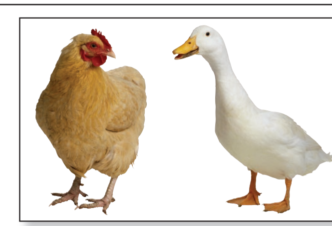
In 2007, the American Association for the Advancement of Science initiated a series of regional conversations with more than 200 biology faculty to discuss how to improve undergraduate biology education. In 2009, using the findings of these regional conversations, the organization held a conference called "Vision and Change in Undergraduate Biology Education." More than 500 biology faculty, college and university administrators, representatives of professional societies, and students and postdoctoral scholars from around the country attended the conference. The proceedings led to various recommendations that can be found at http://visionandchange.org.

A key outcome of "Vision and Change" was the identification of five core concepts of biology (**Figure 1.4**):

1. ***Evolution:*** The diversity of life evolved over time by processes of mutation, natural selection, and genetic exchange.
2. ***Structure and function:*** Basic units of structure define the function of all living things.

(a) Evolution:
Biological evolution, or simply evolution, refers to a heritable change in a population of organisms from generation to generation. As a result of evolution, populations become better adapted to the environment in which they live. For example, the long snout of an anteater is an adaptation that enhances its ability to obtain food, namely ants, from hard-to-reach places. Over the course of many generations, the fossil record indicates that the long snout occurred via biological evolution in which modern anteaters evolved from populations of organisms with shorter snouts.

(b) Structure and function:
Biologists often say "structure determines function." This core concept pertains to very tiny biological molecules and to very large biological structures. The feet of different birds provide a striking example. Aquatic birds have webbed feet that function as paddles for swimming. By comparison, the feet of nonaquatic birds are not webbed and are better adapted for grasping food, perching on branches, and running along the ground. The structure of a bird's feet, webbed versus non-webbed, is a critical feature that affects their function.



(c) Information:
Genetic material composed of DNA (deoxyribonucleic acid) provides a blueprint for the organization, development, and function of living things. During reproduction, a copy of this blueprint is transmitted from parents to offspring. DNA is heritable, which means that offspring inherit DNA from their parents. A key feature of reproduction is that offspring tend to have characteristics that greatly resemble those of their parent(s). As seen here, this mother dolphin and her offspring have strikingly similar features.

(d) Energy and matter:
All living organisms acquire energy and matter from the environment and use them to synthesize essential molecules and maintain the organization of their cells and bodies. These sunflower plants carry out photosynthesis in which they capture light energy and acquire carbon dioxide and water, thereby allowing them to make carbohydrates. This process provides energy and organic molecules so the plants can grow and produce beautiful flowers.

(e) Systems:
When the parts of an organism interact with each other or with the external environment to create novel structures and functions, the resulting characteristics are called emergent properties. For example, the human eye is composed of many different types of cells that are organized to sense incoming light and transmit signals to the brain. Our ability to see is an emergent property of this complex arrangement of different cell types. Biologists use the term systems biology to describe the study of how new properties of life arise by complex interactions of its individual parts.

Figure 1.4 **Core concepts of biology, as advocated by "Vision and Change."** These core concepts will be emphasized throughout this textbook. a: ©Lucas Leuzinger/Shutterstock; b: ©G.K. & Vikki Hart/Getty Images; c: ©Image Source/Getty Images; d: Source: Photo by Bruce Fritz, USDA-ARS; e: ©Maria Teijeiro/Getty Images

3. ***Information flow, exchange, and storage:*** The growth and behavior of organisms are activated through the expression of genetic information.
4. ***Pathways and transformations of energy and matter:*** Biological systems grow and change via processes that are based on chemical transformation pathways and are governed by the laws of thermodynamics.
5. ***Systems:*** Living systems are interconnected and interacting.

A key goal of this textbook is to bring to life these five core concepts of biology. These concepts will be highlighted in each chapter with a "Vision and Change" icon, , which indicates subsections and figures that focus on one or more of these five core concepts.

1.3 Biological Evolution

Learning Outcomes:

1. Explain two mechanisms by which evolutionary change occurs: vertical descent with mutation and horizontal gene transfer.
2. Describe how changes in genomes and proteomes underlie evolutionary changes.

Unity and diversity are two words that often are used to describe the living world. All modern forms of life display a common set of characteristics that distinguish them from nonliving objects. In this section, we will explore how this unity of common traits is rooted in the phenomenon of **biological evolution**, or simply **evolution**, which is a heritable change in a population of organisms from one generation to the next. Life on Earth is united by an evolutionary past in which modern organisms have evolved from populations of pre-existing organisms. This unity is a core concept of biology.

However, evolutionary unity does not mean that organisms are exactly alike. The Earth has many different types of environments, ranging from tropical rain forests to salty oceans, hot and dry deserts, and cold mountaintops. Diverse forms of life have evolved in ways that help them prosper in the different environments the Earth has to offer. In this and the following section, we will begin to examine the unity and diversity that exists within the biological world.

Modern Forms of Life Are Connected by an Evolutionary History

Life began on Earth as primitive cells about 3.5–4 billion years ago (bya). Since that time, populations of living organisms have undergone evolutionary changes that ultimately gave rise to the species we see today. Understanding the evolutionary history of species can provide key insights into the structure and function of an organism's body, because evolutionary change frequently involves modifications of characteristics in pre-existing populations. Over long periods of time, populations may change so that structures with a particular function become modified to serve a new function. For example, the wing of a bat is used for flying, and the flipper of a dolphin is used for swimming. Evidence from the fossil record indicates that both structures were modified from a front limb that was used for walking in a pre-existing ancestor (**Figure 1.5**).

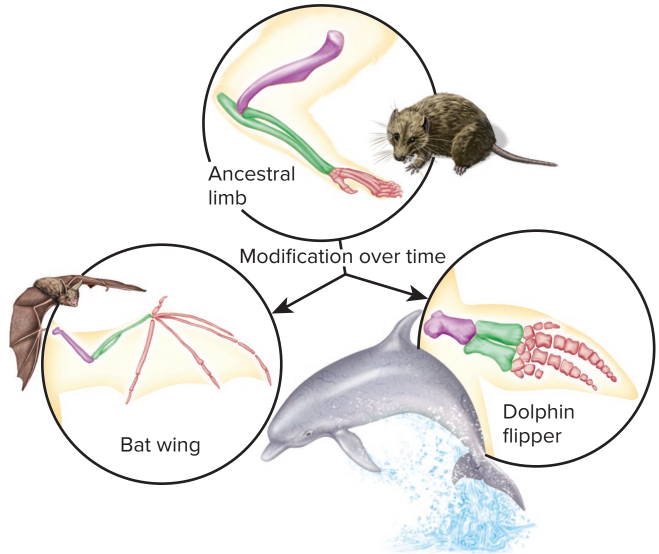


Figure 1.5 An example of a modification that has occurred as a result of biological evolution. The wing of a bat and the flipper of a dolphin are modifications of a limb that was used for walking in a pre-existing ancestor.

Core Concepts: Evolution, Structure and Function Via evolution, the different structures of the front limbs seen here result in functions that are best suited for these organisms.

Evolutionary Change Involves Changes in the Genetic Material

The example shown in Figure 1.5 represents evolution at the macroscopic level. At the molecular level, evolution involves changes in the genetic material, which is composed of **DNA (deoxyribonucleic acid)**. DNA provides a blueprint for the organization, development, and function of living things. During reproduction, a copy of this blueprint is transmitted from parent to offspring. DNA is **heritable**, which means that offspring inherit DNA from their parents.

As discussed in Unit III, **genes**, which are segments of DNA, govern the characteristics, or traits, of organisms. Most genes are transcribed into a type of **RNA (ribonucleic acid)** molecule called messenger RNA (mRNA), which is then translated into a **polypeptide** with a specific amino acid sequence. A **protein** is composed of one or more polypeptides. The structures and functions of proteins play a key role in determining the traits of organisms.

On relatively rare occasions, changes may occur in DNA. A **mutation** is a heritable change in the genetic material—one that can be passed from cell to cell or from parent to offspring. Mutations can alter the properties of genes and thereby affect the characteristics of the offspring that inherit them. With regard to survival, mutations can be beneficial, detrimental, or neutral. As described next, changes in the genetic material underlie the process of evolution.

Changes to the Genetic Material during Evolution May Occur in Different Ways

As a given species evolves and as new species are formed, different types of mechanisms may cause changes in the genetic material. Two common mechanisms are vertical descent with mutation and horizontal gene transfer. Let's take a brief look at each one.

Vertical Descent with Mutation The traditional way to study evolution is to examine a progression of changes in a series of related ancestral species. Such a series is called a **lineage**. **Figure 1.6** shows a portion of the lineage that gave rise to modern horses. This type of evolution is called **vertical evolution** because it occurs in a lineage. Biologists have traditionally depicted such evolutionary change in a diagram like the one shown in Figure 1.6. In this mechanism of evolution, new species evolve from pre-existing ones by the accumulation of mutations. But why would some mutations accumulate in a population and eventually change the characteristics of an entire species? One reason is that a mutation may alter the traits of organisms in a way that increases their chances of survival and reproduction. When a mutation causes such a beneficial change, the frequency of the mutation may increase in a population from one generation to the next, a process called **natural selection**. This topic is discussed in Units IV and V. Evolution also involves the accumulation of neutral changes that do not benefit or harm a species, and evolution sometimes involves rare changes that may be harmful.

With regard to the horses shown in Figure 1.6, the fossil record has revealed adaptive changes in various traits such as size and tooth morphology. The first horses were the size of dogs, whereas modern horses typically weigh more than a half ton. The teeth of *Hyracotherium* were relatively small compared with those of modern horses. Over the course of millions of years, horses' teeth have increased in size, and a complex pattern of ridges has developed on the molars. How do evolutionary biologists explain these changes in horse characteristics? They can be attributed to natural selection, in which changing global climates favored the survival and reproduction of horses with certain types of traits. Over North America, where much of horse evolution occurred, large areas changed from dense forests to grasslands.

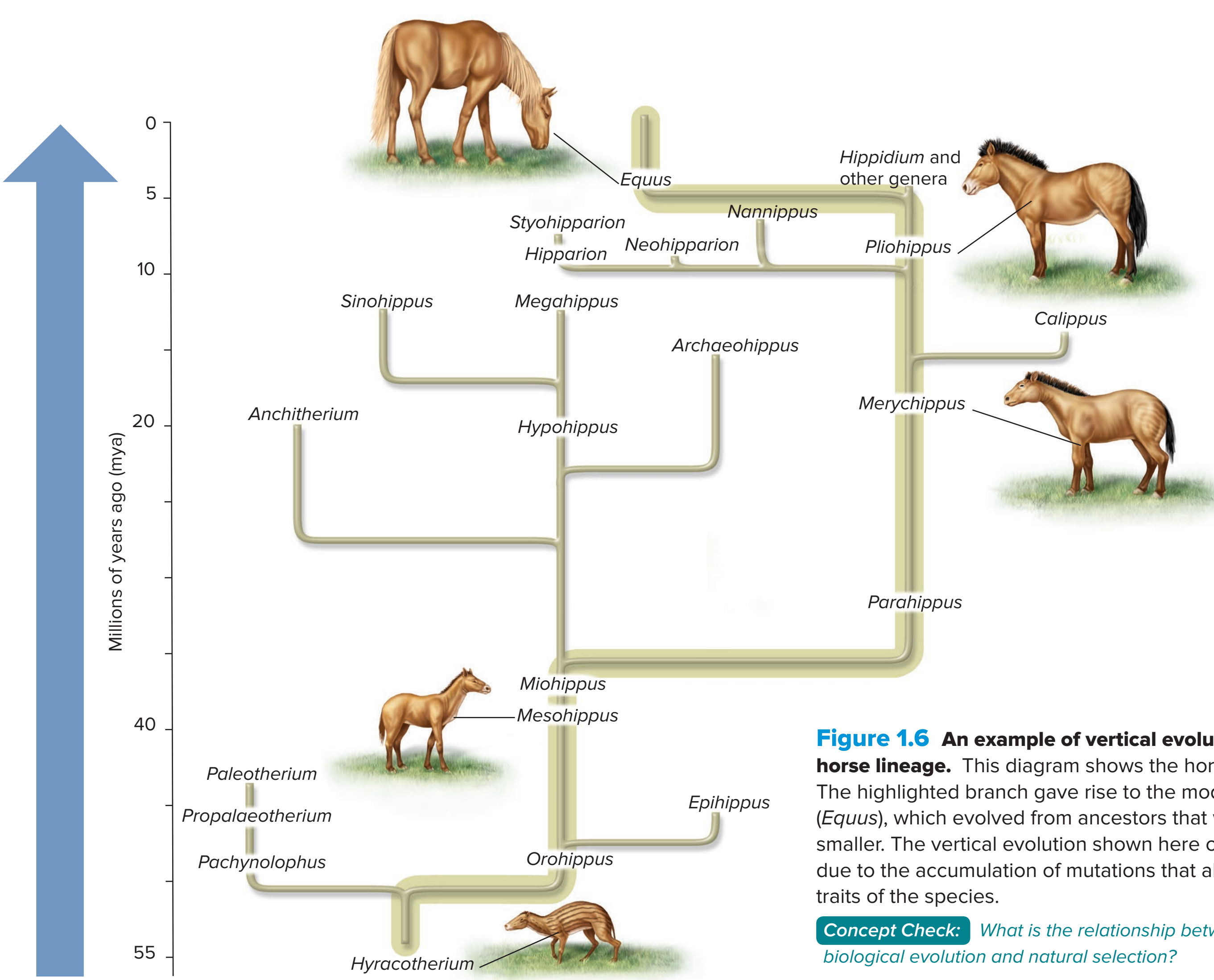


Figure 1.6 An example of vertical evolution: the horse lineage. This diagram shows the horse lineage. The highlighted branch gave rise to the modern horse (*Equus*), which evolved from ancestors that were much smaller. The vertical evolution shown here occurred due to the accumulation of mutations that altered the traits of the species.

Concept Check: *What is the relationship between biological evolution and natural selection?*

Horses with genetic variation that made them larger were more likely to escape predators and to be able to travel greater distances in search of food. The changes seen in horses' teeth are consistent with a dietary shift from eating tender leaves to eating grasses and other types of vegetation that are more abrasive and require more chewing.

Horizontal Gene Transfer The most common way for genes to be transferred is in a vertical manner. This can involve the transfer of genetic material from a mother cell to daughter cells, or it can occur via gametes—sperm and egg—that unite to form a new organism. However, as discussed in later chapters, genes are sometimes transferred between organisms by other mechanisms. These other mechanisms are collectively known as **horizontal gene transfer**, which is the transfer of genetic material from one organism to another organism that is not its offspring. In some cases, horizontal gene transfer can occur between members of different species. For example, you may have heard in the news media that resistance to antibiotics among bacteria is a growing medical problem. As discussed in Chapter 19, genes that confer antibiotic resistance are sometimes transferred between different bacterial species (**Figure 1.7**).

Genes transferred horizontally may be subject to natural selection and promote changes in an entire species. This has been an important mechanism of evolutionary change, particularly among bacterial species. In addition, during the early stages of evolution, which occurred a few billion years ago, horizontal gene transfer was an important part of the process that gave rise to all modern species.

Traditionally, biologists have described evolution using diagrams that depict the vertical evolution of species on a long time scale. This type of evolutionary tree was shown earlier in Figure 1.6. For many decades, a simplistic view held that all living organisms evolved from a common ancestor, resulting in a "tree of life" that depicted the vertical evolution that gave rise to all modern species. Now that we understand the great importance of horizontal gene transfer in the evolution of life on Earth, biologists have re-evaluated the way evolution has occurred over time. Rather than a tree of life, a more appropriate way to view the unity of living organisms is as a "web of life," as shown in **Figure 1.8**, which accounts for both vertical descent and horizontal gene transfer. In a lineage in which the time scale is depicted on a vertical axis, horizontal gene transfer between different species is shown as a horizontal line.

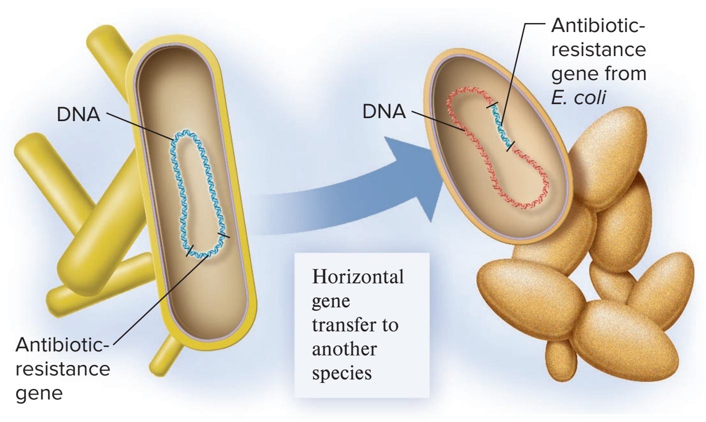


Figure 1.7 An example of horizontal gene transfer: antibiotic resistance. One bacterial species may transfer a gene, such as a gene that confers resistance to an antibiotic, to another bacterial species.

Core Concept: Evolution

The Study of Genomes and Proteomes Provides an Evolutionary Foundation for Our Understanding of Biology

As we have seen, evolutionary unity is a core concept of biology. We can understand the unity of modern organisms by realizing that all living species evolved from an interrelated group of ancestors. However, from an experimental perspective, this realization presents a dilemma—we cannot take a time machine back over the course of 4 billion years to carefully study the characteristics of extinct organisms and fully appreciate the series of changes that have led to modern species. Fortunately, though, evolution has given biologists some wonderful puzzles to study, including the fossil record and the genomes of modern species.

The term **genome** refers to the complete genetic composition of an organism or species (**Figure 1.9a**). The genomes of bacteria and archaea usually contain a few thousand genes, whereas those of eukaryotes may contain tens of thousands. A genome is critical to life because it performs these functions:

- *Stores information in a stable form:* The genome of every organism stores information that provides a blueprint for producing that organism's characteristics.
- *Provides continuity from generation to generation:* The genome is copied and transmitted from generation to generation.
- *Acts as an instrument of evolutionary change:* Every now and then, the genome undergoes a mutation that may alter the characteristics of an organism. In addition, a genome may acquire new genes by horizontal gene transfer. The accumulation of genome changes from generation to generation produces the evolutionary changes that alter species and produce new species.

An exciting advance in biology over the past couple of decades has been the ability to analyze the DNA sequence of genomes, a technology called **genomics**. For example, a researcher can compare the genomes of a frog, a giraffe, and a petunia and discover intriguing similarities and differences. These comparisons help us to understand how new traits evolved. All three types of organisms have the same kinds of genes needed for the breakdown of nutrients such as sugars. In contrast, only the petunia has genes that allow it to carry out photosynthesis. Also, genomics helps us to understand evolutionary relationships. As discussed later in this chapter, researchers analyzed the genomes of giraffes across Africa and concluded that they constitute four distinct species.

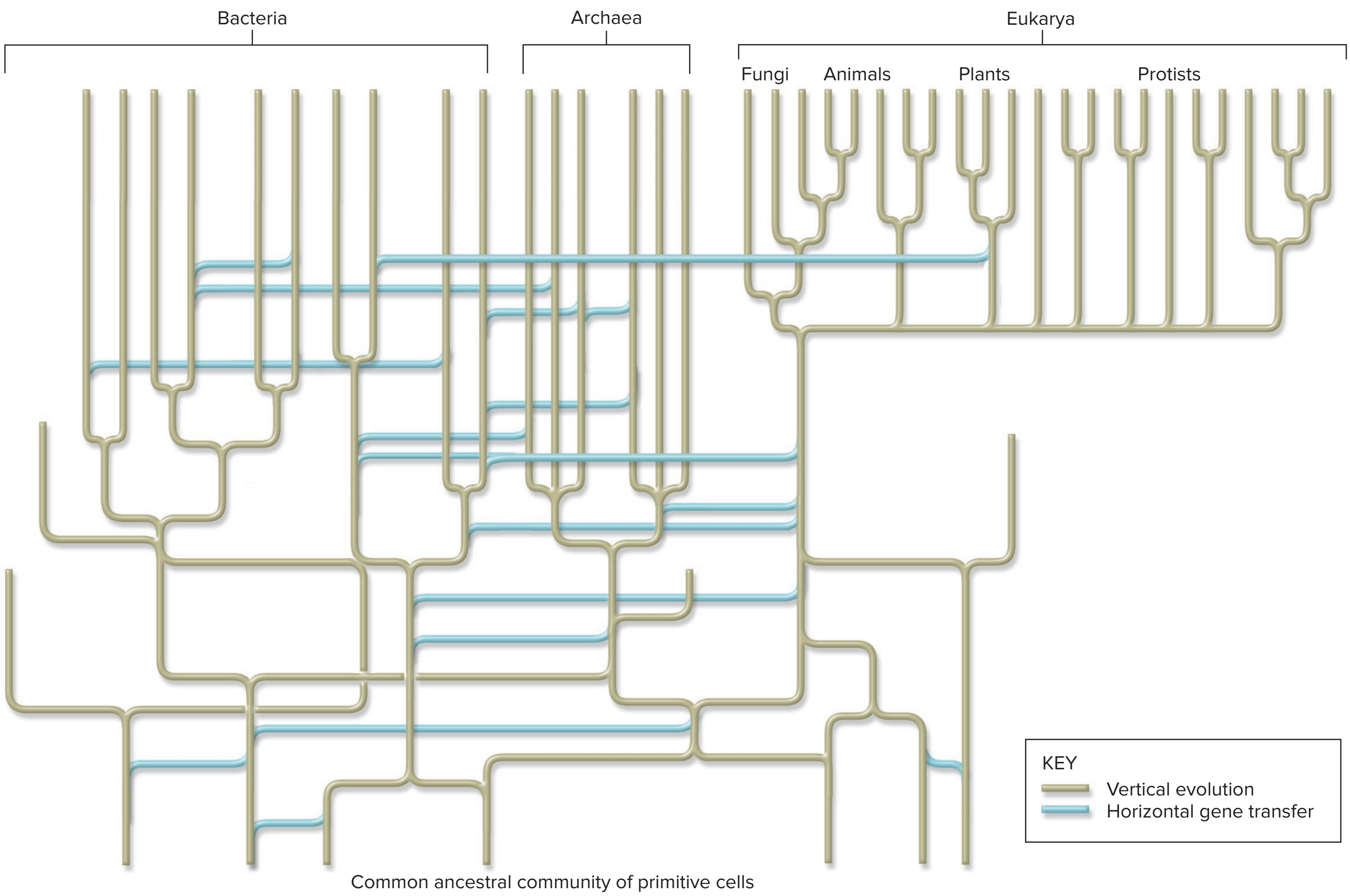


Figure 1.8 The web of life, showing both vertical descent and horizontal gene transfer. This diagram includes both of these important mechanisms in the evolution of life on Earth. Note: Archaea are unicellular species that are similar in cell structure to bacteria.

Concept Check: *How does the concept of a tree of life differ from that of a web of life?*

An extension of genome analysis is the study of the **proteome**, which refers to all of the proteins that a cell or organism makes. The function of most genes is to encode polypeptides that become units in proteins. As shown in **Figure 1.9b**, these include proteins that form a cytoskeleton and proteins that function in cell organization and as enzymes, transport proteins, cell-signaling proteins, and extracellular proteins. The genome of each species carries the information to make its proteome—the hundreds or thousands of proteins that each cell of that species makes. Proteins are largely responsible for the structures and functions of cells and organisms. The set of techniques known as **proteomics** allows researchers to analyze the proteome of a single species and compare the proteomes of different species. Proteomics helps us understand how the various levels of biology are related to one another, from the molecular level—at the level of protein molecules—to higher levels, such as how the functioning of proteins produces the characteristics of cells and organisms and affects the ability of populations of organisms to survive in their natural environments.

1.4 Classification of Living Things

Learning Outcome:

1. Outline how organisms are classified.

As biologists study species and discover new species, they try to place them into groups based on their evolutionary history. This is a difficult task because researchers estimate that the Earth has between 5 and 50 million different species! The rationale for classification is based on vertical descent. Species with a recent common ancestor are grouped together, whereas species whose common ancestor was in the very distant past are placed into different groups. The field of biology that is concerned with the grouping and classification of species is termed **taxonomy**.

Why is taxonomy useful? First, taxonomy allows use to appreciate the amazing diversity of life on Earth. Also, because taxonomy is based on evolution, it provides a view of the evolutionary relationships among living species, and between living and extinct species.

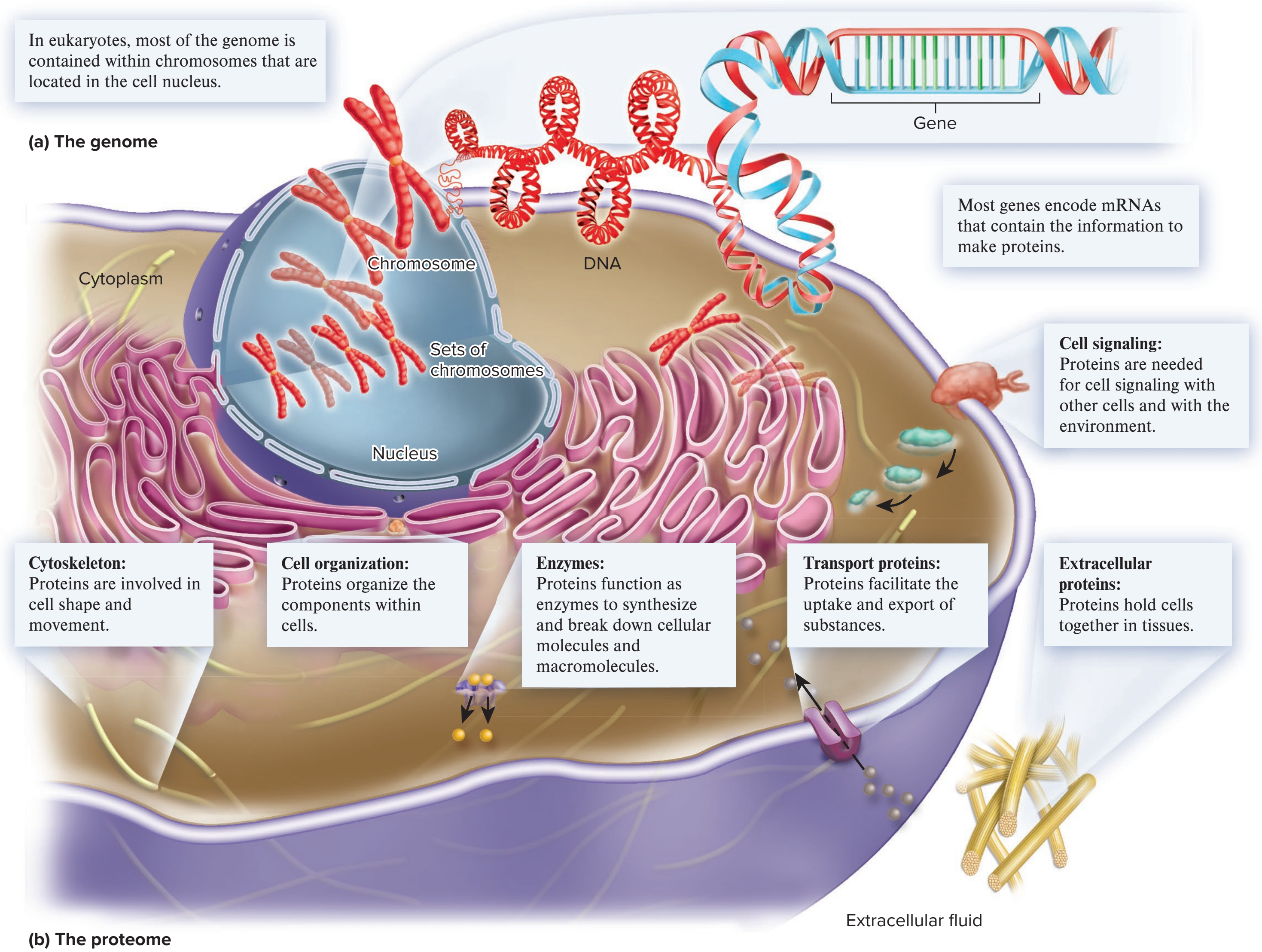


Figure 1.9 **Genomes and proteomes.** **(a)** The genome, which is composed of DNA, is the entire genetic composition of an organism. Most of the genetic material in eukaryotic cells is found in the cell nucleus. The primary function of the genome is to encode the proteome **(b)**, which is the entire protein complement of a cell or organism. Six general categories of proteins are illustrated. Proteins are largely responsible for the structure and function of cells and organisms.

Concept Check: *Biologists sometimes say that the genome is the storage unit of life, whereas the proteome is largely the functional unit of life. Explain this statement.*

The Classification of Living Organisms Allows Biologists to Appreciate the Unity and Diversity of Life

Let's first consider taxonomy on a broad scale. You may have noticed that Figure 1.8 showed three main groups of organisms. From an evolutionary perspective, all forms of life can be placed into those three large categories, or domains, called **Bacteria**, **Archaea**, and **Eukarya** (**Figure 1.10**). Bacteria and archaea are microorganisms that are also termed **prokaryotic** because their cell structure is relatively simple. At the molecular level, bacterial and archaeal cells show significant differences in their compositions. By comparison, organisms in the domain Eukarya are **eukaryotic** and have cells with internal compartments that serve various functions. A defining distinction between prokaryotic and eukaryotic cells is that eukaryotic cells have a **cell nucleus** in which the genetic material is surrounded by a membrane.

The organisms in domain Eukarya were once subdivided into four major categories, or kingdoms, called Protista (protists), Plantae (plants), Fungi, and Animalia (animals). However, as discussed in Chapter 25 and Unit V, this traditional view became invalid as biologists gathered new information regarding the evolutionary relationships of these organisms. We now know that the protists do not form a single kingdom but instead are divided into several broad categories called supergroups.

Taxonomy involves multiple levels in which particular species are placed into progressively smaller and smaller groups whose