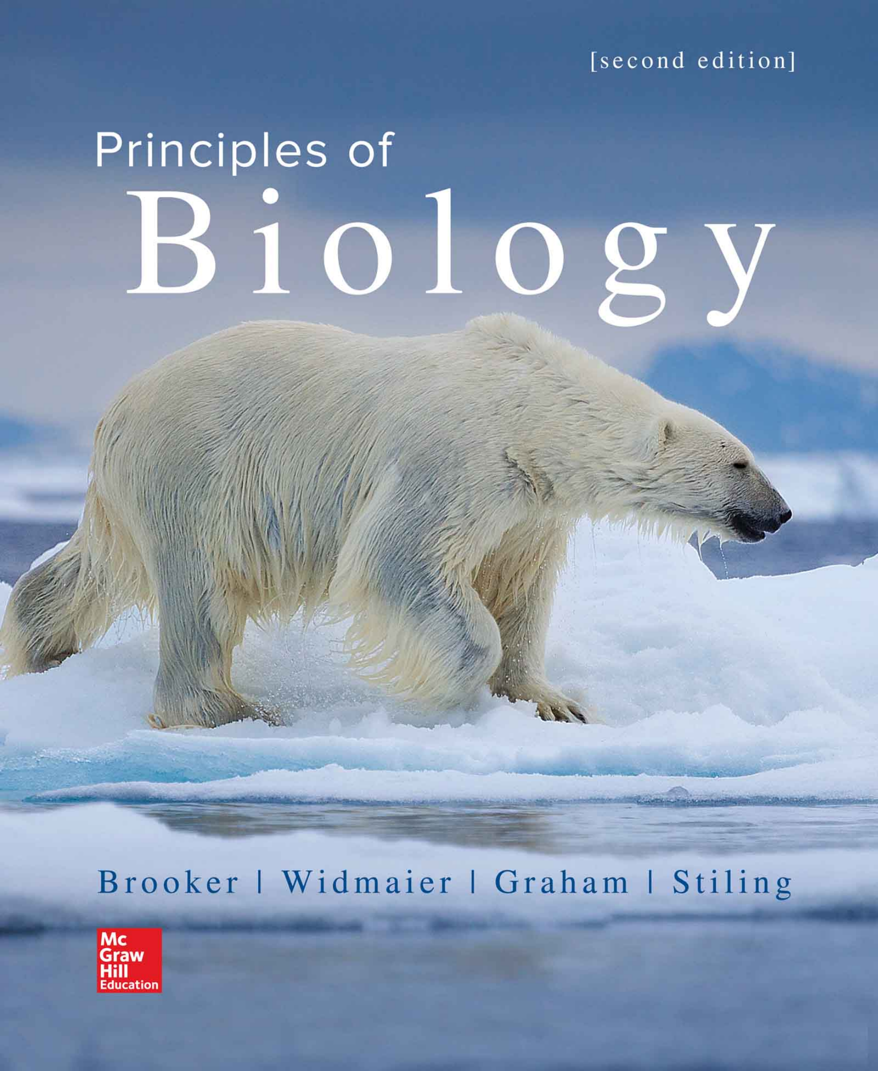
[second edition]

Principles of Biology



Brooker | Widmaier | Graham | Stiling

Mc Graw Hill Education

[second edition]

Principles of Biology

Robert J. Brooker
University of Minnesota - Minneapolis

Eric P. Widmaier
Boston University

Linda E. Graham
University of Wisconsin - Madison

Peter D. Stiling
University of South Florida

Mc Graw Hill Education

PRINCIPLES OF BIOLOGY, SECOND EDITION

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About the Authors

Robert J. Brooker

Rob Brooker received his Ph.D. in genetics from Yale University in 1983. 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 At the University of Minnesota, Dr. Brooker teaches undergraduate courses in biology and genetics. In addition to many other publications, he has written two undergraduate genetics texts: *Genetics: Analysis & Principles*, Sixth Edition, copyright 2018, and *Concepts of Genetics*, Second Edition, copyright 2015; and he is the lead author of *Biology*, Fourth Edition, copyright 2017, all published by McGraw-Hill Education.

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

Eric P. Widmaier

Eric Widmaier received his Ph.D. in 1984 in endocrinology from the University of California at San Francisco. His 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 courses in human physiology, comparative physiology, and endocrinology and recently received the university's highest honor for excellence in teaching. Among other publications, he is a coauthor of *Vander's Human Physiology: The Mechanisms of Body Function*, Fourteenth Edition, copyright 2017; and *Biology*, Fourth Edition, copyright 2017, both published by McGraw-Hill Education.

Linda E. Graham

Linda Graham received her Ph.D. in botany from the University of Michigan, Ann Arbor. Her research explores the evolutionary origin of algae land-adapted plants, focusing on their cell and molecular biology as well as ecological interactions with microbes. Dr. Graham is now Professor of Botany at the University of Wisconsin–Madison. She teaches undergraduate courses in microbiology and plant biology. She is the coauthor of, among other publications, *Algae*, Third Edition, copyright 2015, a major's textbook on algal biology; and *Plant Biology*, Third Edition, copyright 2015, both published by LJLM Press. She is also a coauthor of *Biology*, Fourth Edition, copyright 2017, published by McGraw-Hill Education.

Peter D. Stiling

Peter Stiling obtained his Ph.D. from University College, Cardiff, Wales, in 1979. 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. During this time, he began photographing and writing about butterflies and other insects, which led to publication of several books on local insects. Dr. Stiling is currently a Professor of Biology at the University of South Florida at Tampa. His research interests include plant-insect relationships, parasite-host relationships, biological control, restoration ecology, and the effects of elevated carbon dioxide levels on plant–herbivore interactions. He teaches graduate and undergraduate courses in ecology and environmental science as well as introductory biology. He has published many scientific papers and is the author of *Ecology: Global Insights and Investigations*, Second Edition, copyright 2015, and is coauthor of *Biology*, Fourth Edition, copyright 2017, both published by McGraw-Hill Education.

Ian Quitadamo, Lead Digital Author

Ian Quitadamo is a Professor with a dual appointment in Biological Sciences and Science Education at Central Washington University in Ellensburg, Washington. He teaches introductory and majors biology courses and cell biology, genetics, and biotechnology, as well as science teaching methods courses for future science teachers and interdisciplinary content courses in alternative energy and sustainability. Dr. Quitadamo was educated at Washington State University and holds a BA in biology, Masters degree in genetics and cell biology, and an interdisciplinary Ph.D. in science, education, and technology. Previously a researcher of tumor angiogenesis, he now investigates the behavioral and neurocognitive basis of critical thinking and has published numerous studies of factors that improve student critical thinking performance. He has received the Crystal Apple award for teaching excellence, led multiple initiatives in critical thinking and assessment, and is active nationally in helping transform university faculty practice.

A Note about *Principles of Biology* . . .

A recent trend in science education is the phenomenon called "flipping the classroom." This phrase refers to the idea that some of the activities that used to be done in class are now done out of class, and vice versa. For example, instead of spending the entire class time lecturing about textbook and other materials, some of the class time is spent engaging students in various activities, such as problem solving, working through case studies, and designing experiments. This approach is called active learning. For many instructors, the classroom has become more learner-centered rather than teacher-centered. A learner-centered classroom provides a rich environment in which students can interact with each other and with their instructors. Instructors and fellow students often provide formative assessment—immediate feedback that helps each student understand if his or her learning is on the right track.

What are some advantages of active learning? Educational studies reveal that active learning usually promotes greater learning gains. In addition, active learning often focuses on skill development rather than the memorization of facts that are easily forgotten. Students become trained to "think like scientists" and to develop a skill set that enables them to apply scientific reasoning.

A common concern among instructors who are beginning to try out active learning is that they think they will have to teach their students less material. However, this may not be the case. Although students may be provided with online lectures, "flipping the classroom" typically gives students more responsibility for understanding the textbook material on their own. Along these lines, *Principles of Biology* is intended to provide students with a resource that can be effectively used out of the classroom. Several key pedagogical features include the following:

- **Focus on Core Concepts:** Although it is intended for majors in the biological sciences, *Principles of Biology* is a shorter textbook that emphasizes core concepts. Twelve principles of biology are enunciated in Chapter 1 and those principles are emphasized throughout the textbook with specially labeled figures. An effort has also been made to emphasize some material in bulleted lists and numbered lists, so students can more easily see the main points.
- **Learning Outcomes:** Each section of every chapter begins with a set of learning outcomes. These outcomes help students understand what they should be able to do if they have mastered the material in that section. Certain learning outcomes, labeled as **SCISKILLS**, emphasize experimental skills needed in the study of biology. Skills such as *analyze data, form hypotheses, make predictions, make calculations,* are skills that scientists generally perform and students majoring in biology should practice.
- **Formative Assessment:** When students are expected to learn textbook material on their own, it is imperative that they be given regular formative assessments so they can gauge whether or not they are mastering the material. Formative assessment is a major feature of this textbook and is bolstered by McGraw-Hill Connect®—a state-of-the-art digital assignment and assessment platform. In *Principles of Biology*, formative assessment is provided in multiple ways.

    1. Each section of every chapter ends with multiple-choice questions.
    2. Most figures have concept check questions so students can determine if they understand the key points in the figure.
    3. End-of-chapter questions continue to provide students with feedback regarding their mastery of the material.
    4. Further assessment tools are available in Connect. Question banks, Test banks, and Quantitative Question banks can be assigned by the professor. McGraw-Hill SmartBook® allows for individual study as well as assignments from the professor.

- **Quantitative Analysis:** Many chapters have a subsection that emphasizes quantitative reasoning, an important skill for careers in science and medicine. In these subsections, the quantitative nature of a given topic is described, and then students are asked to solve a problem related to that topic.
- **BioConnections and Evolutionary Connections:** To help students broaden their understanding of biology, two recurring features are BioConnections and Evolutionary Connections. BioConnections are placed in key figure legends in each chapter and help students relate a topic they are currently learning to another topic elsewhere in the textbook, often in a different unit. Evolutionary Connections provide a framework for understanding how a topic in a given chapter relates to evolution, the core unifying theme in biology.

- New **BioTIPS:** In Connect, the digital partner to this textbook, we have a new feature called **BioTIPS**, which is intended to help students refine problem-solving skills. Most of the **BioTIPS** are called out with icons in the textbook, but additional **BioTIPS** are included in the SmartBook. The **BioTIPS** themselves are accessed through links in SmartBook. **BioTIPS** will focus on 11 strategies that will help students solve problems:

  1. ***Make a drawing***.
  2. ***Compare and contrast***.
  3. ***Relate structure and function***.
  4. ***Sort out the steps in a complicated process***.
  5. ***Propose a hypothesis***.
  6. ***Design an experiment***.
  7. ***Predict the outcome***.
  8. ***Interpret data***.
  9. ***Use statistics***.
  10. ***Make a calculation***.
  11. ***Search the literature.***

BioTIPS will provide students with practice at applying these problem-solving strategies.

Overall, the pedagogy of *Principles of Biology* has been designed to foster student learning. Instead of being a collection of "facts and figures," *Principles of Biology* is intended to be an engaging and motivating textbook in which formative assessment allows students to move ahead and learn the material in a productive way.

Content Changes to the Second Edition

The author team of *Principles of Biology* is fully committed to keeping the content up to date; the second edition has five new chapters that reflect modern trends in the field. They are intended to achieve three goals:

- **Prepare Students for Careers in Modern Biology:** Chapters 11, 16, and 24 are concerned with the topics of Non-coding RNAs, Epigenetics, and Microbiomes, respectively. The emerging importance of these areas in the field of medicine is dramatic. It's difficult to pick up a newspaper and not see a story that concerns at least one of these areas and its impact on human health. For example, researchers are now studying how the manipulation of certain non-coding RNAs may be used as therapeutic tools to treat diseases such as cancer. Similarly, these same topics have broad importance in the fields of agriculture, biotechnology, and environmental science.
- **An Emphasis on Systems Biology:** The first edition of *Principles of Biology* already had an emphasis on systems biology and trying to relate topics in biology to its evolutionary foundation. In the second edition, we have added a new chapter to the animal unit (Chapter 41) that explores how the whole body responds to a major challenge to homeostasis (hemorrhage). This allows students to appreciate how various organs and organ systems work together as a larger integrated system—the animal body.
- **Impact on Society:** Not only do we want to help our students learn biology and prepare them for careers in this field, we also want them to appreciate their roles as citizens of the world. Chapter 46 pulls together many of the key topics involving the impact of humans on the environment, thereby making students aware of current and future problems. This chapter may inspire some students to pursue a career in ecology or environmental science, and may encourage others to educate the public regarding the negative effects that humans have had on the environment and ways to evoke positive changes.

To make room for this material and other updated material, some chapters have been streamlined and combined, and obsolete methods have given way to new techniques described in these new chapters. The major content changes that have occurred in the second edition are summarized below.

Chapter 1 An Introduction to Biology. Has a new section on the adaptations that have occurred during the evolution of polar bears.

Chapter 4 Evolutionary Origin of Cells and their General Features. This chapter now begins with a section on the evolutionary origin of cells.

NEW Chapter 11 The Expression of Genetic Information via Genes II: Non-coding RNAs. This "first of its kind chapter" recognizes the great importance of non-coding RNAs in biology and devotes an entire chapter to this topic. The author team feels it is long overdue.

NEW Chapter 16 Transmission of Genetic Information from Parents to Offspring II: Epigenetics, Linkage, and Extranuclear Inheritance. Due to the rapidly expanding topic of epigenetics, the inheritance chapter in the first edition has been split into two chapters. Chapter 16, which is the second chapter devoted to inheritance, has four sections on epigenetics and also includes the topics of linkage and extranuclear inheritance.

Chapter 18 Genetic Technologies: How Biologists Study Genes and Genomes. Has a new section on CRISPR-Cas technology, which is used to introduce mutations into genes.

Chapter 19 Evolution of Life I: How Populations Change from Generation to Generation. The Evolution unit has been reorganized so that it now begins with a description of the basic mechanisms that underlie evolutionary change.

Chapter 22 The History of Life on Earth and Human Evolution. The topic of human evolution has been moved from the Diversity unit to the Evolution unit. The description of human evolution has been greatly expanded, and has new topics including how humans are still evolving and the level of genetic variation in modern human populations.

Chapter 23 Diversity of Microbial Life: Archaea, Bacteria, Protists, and Fungi. This chapter on the diversity of prokaryotic and eukaryotic microbial life has been heavily revised to integrate material previously covered in separate chapters. Newer concepts of phylogenetic diversification of these groups have been incorporated into evolutionary tree diagrams.

This revision provides several pedagogical advantages. A focus on microbial diseases of humans and crops, a continuing thread through coverage of bacteria, and also protists and fungi, reveals greater pathogen diversity than students may previously have realized. The diversity of technological applications involving microbes, previously described in several separate places, has now been aggregated at the end of the chapter. Long important in terms of food or antibiotic production, microbial applications are now taking on new relevance to the fields of environmental pollution control and renewable biofuels.

Finally, by integrating fundamental aspects of four microbial groups, Chapter 23 now provides the broad diversity background necessary to comprehend microbiomes, a topic of vast medical, ecological, and technological importance that is presented in a new chapter.

NEW Chapter 24 Microbiomes: Microbial Systems on and Around Us. This entirely new chapter integrates information about the occurrence of microbes (archaea, bacteria, protists, and fungi) within complex organism-gene systems known as microbiomes, a major frontier of biological sciences. The new chapter expands the much briefer and scattered introductions to symbiotic relationships between microbes, plants, and animals presented in the first edition. New Chapter 24 begins by linking basic information on microbial life provided in Chapter 23 with important environments in which microbiomes occur: physical environments such as oceans, ice, and soils, and biotic environments that include the bodies of humans and agricultural plants. The new chapter then focuses on genetic methods that microbiologists use to comprehend and compare Earth's microbiomes. This helps students to review and extend basic genetics presented earlier in the text and understand important applications of genetic and genomic technologies. The new chapter also focuses on evolutionary and diversity aspects of microbiomes that are key to fostering agricultural production and human health, thereby connecting students to previous text chapters describing fundamental principles of evolutionary biology.

Chapter 25 Plant Evolution and Diversity. New information about the evolutionary history of plants has been incorporated to maximize currency, without increasing complexity or level of detail. A new **BioTIPS** feature, which aims to foster student understanding of experimental design in the scientific process, has been developed for the popular Feature Investigation on *Cannabis* secondary metabolites, of high societal significance.

Chapter 26 Invertebrates: The Vast Array of Animal Life Without a Backbone. Our animal classification as depicted in Figure 26.2 has been reworked and redrawn to reflect the position of the Ctenophora or comb jellies, as the earliest diverging animal clade. Additional photographs have also been added to Figure 26.12 to illustrate the polyp and medusa form of cnidarians. We have also included a new multi-part figure, Figure 26.32, to illustrate the different echinoderm classes.

Chapter 27 Vertebrates: Fishes, Amphibians, Reptiles and Mammals. The material on primates and human evolution has been moved to Chapter 22, The History of Life on Earth and Human Evolution.

Chapter 28 An Introduction to Flowering Plant Form and Function. A **BioTIPS** feature designed to help students interpret graphical quantitative information has been developed for the Feature Investigation, which focuses on leaf structural variation.

Chapter 29 How Flowering Plants Sense and Interact with Their Environments. Some new images have been incorporated.

Chapter 30 How Flowering Plants Obtain and Transport Nutrients. Some new images have been incorporated.

Chapter 31 How Flowering Plants Reproduce and Develop. A new **BioTIPS** feature, based on the Feature Investigation about flower blooming, not only fosters student ability to interpret graphical quantitative information, but also leads them to make additional calculations to answer new questions about the topic.

Chapter 32 General Features of Animal Bodies, and Homeostasis as a Defining Principle of Animal Biology. This chapter now includes a section entitled "Principles of Homeostasis of Internal Fluids," which has been moved here from later in the Animal Unit where it was previously covered (former Chapter 38). New "Test Yourself" questions and several improved figures and new concept checks have been added.

Chapter 33 Neuroscience I: The Structure, Function, and Evolution of Nervous Systems. New figures, including an electron micrograph of a cross section through a nerve, have been added, while several existing figures have been modified with additional labeling or text boxes to improve clarity. Numerous SCISKILLS features have been incorporated throughout the section-opening learning outcomes.

Chapter 34 Neuroscience II: How Sensory Systems Allow Animals to Interact with the Environment. Numerous subheadings are now interspersed in the chapter to help the reader navigate through difficult passages and to help the instructor and student organize the readings. Numerous SCISKILLS have been incorporated throughout the section-opening learning outcomes, and new concept checks have been added. Throughout the chapter, material has been updated to reflect key new research, particularly with respect to olfaction and balance.

Chapter 35 How Muscles and Skeletons are Adaptations for Movement, Support, and Protection. In addition to numerous SCISKILLS features, a new conceptual question has been added and several figures have been improved for even greater clarity.

Chapter 36 Circulatory and Respiratory Systems: Transporting Solutes and Exchanging Gases. The former chapters on circulation and respiration (chapters 36 and 37) have now been merged into one cohesive chapter that covers both topics in a fully integrated way. As one example, a new table has been added that covers the relationship between an animal's body mass and various respiratory parameters; this table now parallels a similar one that was present in the former Circulatory System chapter that described the relationship between body mass and circulatory features. As with other chapters, numerous SCISKILLS features, figure modifications, and assessments have added or updated. A new figure depicting human bronchioles in health and disease has also been added.

Chapter 37 Digestive and Excretory Systems Help Maintain Nutrient, Water, and Energy Balance and Remove Waste Products from Animal Bodies. The former chapters on digestion and nutrition, and the excretory system, have now been integrated into one chapter. The combined focus is now on nutrient processing and energy balance and the elimination of soluble wastes. Numerous text boxes and figure labels have been adjusted in the artwork to enhance understanding. The advantages and disadvantages of generating a particular type of nitrogenous waste are now elaborated. SCISKILLS features have been added to all sections. Two new concept checks and Bioconnection features have been added.

Chapter 38 How Endocrine Systems Influence the Activities of all Other Organ Systems. Several text boxes, labels and figure legends have been modified for additional detail to improve understanding. SCISKILLS features have been added to each section, and the text has been updated to reflect modern research in endocrinology.

Chapter 39 The Production of Offspring: Reproduction and Development. The Impact on Public Health section has been reorganized with numerous subheadings for clarity. SCISKILLS have been added, as has a new Bioconnections question. Certain key figures have been updated or modified for clarity.

Chapter 40 Immune Systems: How Animals Defend Against Pathogens and Other Dangers. The opening section is now reorganized with subheadings for clarity, and includes discussions of some important animal diseases. Additional new subheadings also break up complex text throughout the chapter. SCISKILLS and a new test question have been added, and key figures have been improved for clarity or detail, or updated (such as latest figures on the number of people living with HIV/AIDS as of today).

NEW Chapter 41 Integrated Responses of Animal Organ Systems to a Challenge to Homeostasis. This new chapter integrates the functions of all organ systems found in animals, using a challenge to homeostasis (hemorrhage) as the central theme. It introduces ten new figures and a new table covering topics such as baroreceptors, chemoreceptors, Starling forces and many others, all in the context of an integrated response to a large homeostatic insult.

Chapter 43: Population Growth and Species Interactions. Two new **BioTIPS** questions have been added to better familiarize students with mark-recapture analyses and competition and resource utilization. The material on human population growth has been moved to Chapter 46. There are three new conceptual and collaborative questions.

Chapter 44: Communities and Ecosystems: Ecological Organization of Large Scales. Chapter 44 has been reworked to include a discussion of both community and ecosystem ecology together in the same chapter. We have combined chapters 45 and 46 from the first edition. However, the material on biogeochemical cycles has been moved to Chapter 46.

Chapter 45: How Climate Affects the Distribution of Species on Earth. This chapter uses elements of Chapter 43: Ecology and the Physical Environment, from the first edition and expands on them. In the first section, 45.1, Climate, we show what causes global temperature and precipitation differentials across the Earth. In the next section, 45.2, Major Biomes, we describe and illustrate the major biomes on Earth.

NEW Chapter 46: The Age of Humans. This is a new chapter. We begin by introducing the concept of a new geological era, the Anthropocene, and then discuss the effects of humans on natural systems. We start with an examination of human population growth, which continues in an upward trend. Next, we explain how humans are contributing to climate change via global warming. This is followed by section 46.3, Pollution and Human Influences on Biogeochemical Cycles. In this section we describe human influences on the carbon, water, phosphorous, and nitrogen cycles from the burning of fossil fuels, the use of chemical fertilizers and pesticides, and other factors. This can lead to biomagnification, as explained next in section 46.4. One of the biggest effects of humans is habitat destruction and in section 46.5 we detail the effects of deforestation and agriculture on wildlife loss. In section 46.6, Overexploitation, we discuss the effects of overhunting and overfishing on land mammals, whales, birds, fishes, and plants. Lastly, in section 46.7, Invasive Species, we consider the many and varied effects of deliberate and accidental plant and animal introductions on native wildlife via competition, predation and parasitism.

Chapter 47: Biodiversity and Conservation Biology. We have updated Table 47.1, which provides details of the world's ecosystem services. The material on causes of extinction and loss of biodiversity has been moved to chapter 46. However, section 47.3, Conservation Strategies, has been expanded to include new material and figures on crisis ecoregions and "last of the wild" in addition to megadiversity countries and biodiversity hot spots.

Guiding You Through *Principles of Biology*

Principles of Biology and its online assets have been carefully crafted to help students work efficiently and effectively through the material in the course, making the most of their study time. This *Guiding You Through Principles of Biology* section explains how students can use the text and Connect® to help them succeed in majors biology.

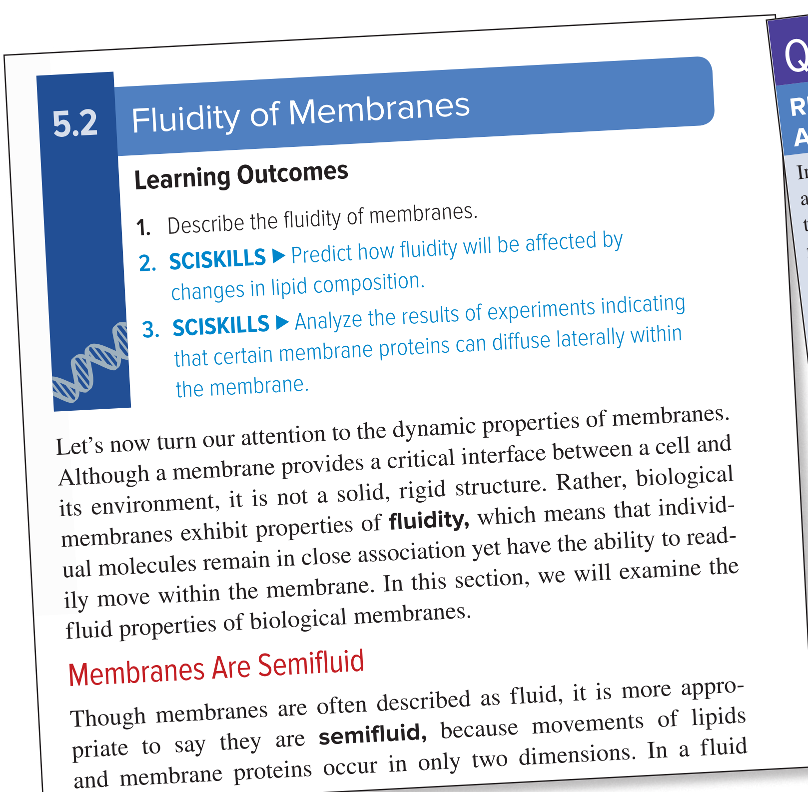
EMPHASIZING SKILLS DEVELOPMENT AND PROBLEM SOLVING

Skills Development

At the beginning of each section, **Learning Outcomes** inform students of concepts they should understand. New to the second edition are skills-based Learning Outcomes. Labeled as **SCISKILLS**, these Learning Outcomes are specific to the skills students will acquire when mastering the material and provide a specific understanding of how such skills may be assessed. SCISKILLS is a mental action such as analyze data, form hypotheses, make predictions, or perform calculations. These are skills scientists generally perform and students should practice.

The emphasis on skills development continues in the **Feature Investigations**. Feature Investigations provide a complete description of experiments, including data analysis, so students can understand how experimentation leads to an understanding of biological concepts.

The **Quantitative Analysis** feature helps develop analytical skills. This feature walks through biological concepts that have a quantitative component. The Crunching the Numbers provides a sample problem to test understanding.



5.2 Fluidity of Membranes

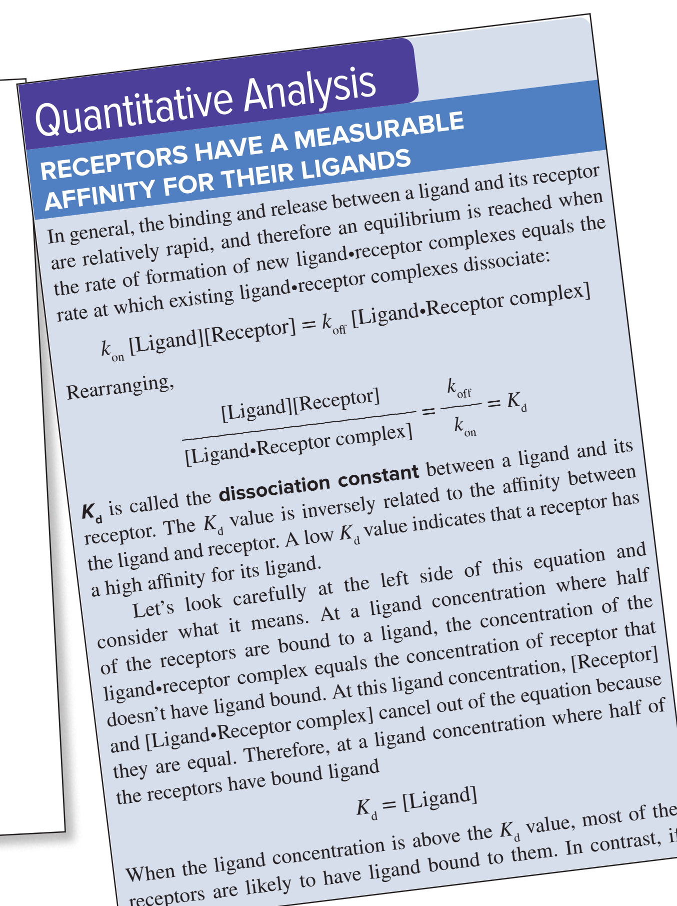
Learning Outcomes

1. Describe the fluidity of membranes.
2. SCISKILLS ▶ Predict how fluidity will be affected by changes in lipid composition.
3. SCISKILLS ▶ Analyze the results of experiments indicating that certain membrane proteins can diffuse laterally within the membrane.

Let's now turn our attention to the dynamic properties of membranes. Although a membrane provides a critical interface between a cell and its environment, it is not a solid, rigid structure. Rather, biological membranes exhibit properties of **fluidity,** which means that individual molecules remain in close association yet have the ability to readily move within the membrane. In this section, we will examine the fluid properties of biological membranes.

Membranes Are Semifluid

Though membranes are often described as fluid, it is more appropriate to say they are **semifluid,** because movements of lipids and membrane proteins occur in only two dimensions. In a fluid



Quantitative Analysis

RECEPTORS HAVE A MEASURABLE AFFINITY FOR THEIR LIGANDS

In general, the binding and release between a ligand and its receptor are relatively rapid, and therefore an equilibrium is reached when the rate of formation of new ligand•receptor complexes equals the rate at which existing ligand•receptor complexes dissociate:

$$k_{on}\,[\text{Ligand}][\text{Receptor}] = k_{off}\,[\text{Ligand•Receptor complex}]$$

Rearranging,

$$\frac{[\text{Ligand}][\text{Receptor}]}{[\text{Ligand•Receptor complex}]} = \frac{k_{off}}{k_{on}} = K_d$$

K_d is called the **dissociation constant** between a ligand and its receptor. The K_d value is inversely related to the affinity between the ligand and receptor. A low K_d value indicates that a receptor has a high affinity for its ligand.

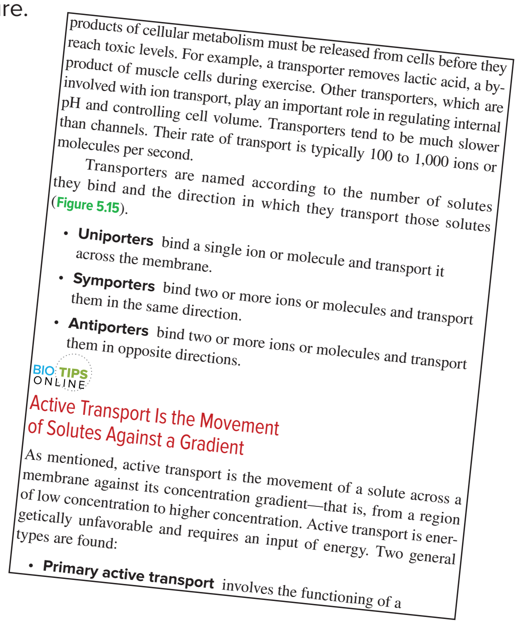
Let's look carefully at the left side of this equation and consider what it means. At a ligand concentration where half of the receptors are bound to a ligand, the concentration of the ligand•receptor complex equals the concentration of receptor that doesn't have ligand bound. At this ligand concentration, [Receptor] and [Ligand•Receptor complex] cancel out of the equation because they are equal. Therefore, at a ligand concentration where half of the receptors have bound ligand

$$K_d = [\text{Ligand}]$$

When the ligand concentration is above the K_d value, most of the receptors are likely to have ligand bound to them. In contrast, if

Problem Solving

A new feature will help students develop their problem solving skills. **BioTIPS**, which stands for **T**opic, **I**nformation, and **P**roblem Solving **S**trategy is a feature available in Connect. Icons appearing throughout the book indicate the textual material supporting the **BioTIPS** online. These solved problems follow a consistent pattern in which students are given advice on how to solve problems in biology using different types of problem solving strategies. These strategies include: 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; and Search the literature.



products of cellular metabolism must be released from cells before they reach toxic levels. For example, a transporter removes lactic acid, a by-product of muscle cells during exercise. Other transporters, which are involved with ion transport, play an important role in regulating internal pH and controlling cell volume. Transporters tend to be much slower than channels. Their rate of transport is typically 100 to 1,000 ions or molecules per second.

Transporters are named according to the number of solutes they bind and the direction in which they transport those solutes (Figure 5.15).

- **Uniporters** bind a single ion or molecule and transport it across the membrane.
- **Symporters** bind two or more ions or molecules and transport them in the same direction.
- **Antiporters** bind two or more ions or molecules and transport them in opposite directions.

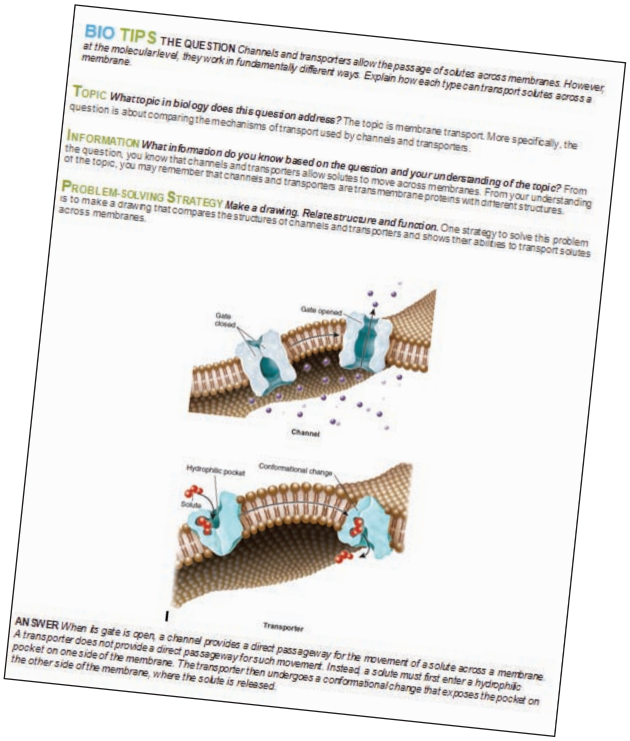
BIO TIPS ONLINE

Active Transport Is the Movement of Solutes Against a Gradient

As mentioned, active transport is the movement of a solute across a membrane against its concentration gradient—that is, from a region of low concentration to higher concentration. Active transport is energetically unfavorable and requires an input of energy. Two general types are found:

- **Primary active transport** involves the functioning of a

A biological question related to chapter content is posed. The **BioTIPS** then walks the student through the process of answering the question. First, they help the student identify the topic of the question—what is really being asked in the question? Then they help the student collect information that was presented in the chapter that is related to the question. Finally, they help the student settle on one or more strategies that can be followed to answer the question. The answers are provided to complete the problem solving process.



BIO TIPS **THE QUESTION** *Channels and transporters allow the passage of solutes across membranes. However, at the molecular level, they work in fundamentally different ways. Explain how each type can transport solutes across a membrane.*

TOPIC ***What topic in biology does this question address?*** The topic is membrane transport. More specifically, the question is about comparing the mechanisms of transport used by channels and transporters.

INFORMATION ***What information do you know based on the question and your understanding of the topic?*** From the question, you know that channels and transporters allow solutes to move across membranes. From your understanding of the topic, you may remember that channels and transporters are transmembrane proteins with different structures.

PROBLEM-SOLVING STRATEGY ***Make a drawing. Relate structure and function.*** One strategy to solve this problem is to make a drawing that compares the structures of channels and transporters and shows their abilities to transport solutes across membranes.

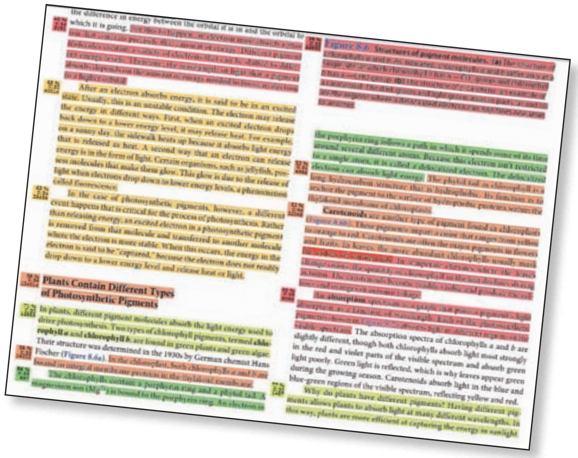
ANSWER *When its gate is open, a channel provides a direct passageway for the movement of a solute across a membrane. A transporter does not provide a direct passageway for such movement. Instead, a solute must first enter a hydrophilic pocket on one side of the membrane. The transporter then undergoes a conformational change that exposes the pocket on the other side of the membrane, where the solute is released.*

USING STUDENT USAGE DATA TO MAKE IMPROVEMENTS

To help guide the revision for the second edition, student usage data and input were used, derived from thousands of SmartBook® users of the first 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 questions.

- 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 questions, the authors revised or reorganized the content to be as clear and illustrative as possible by rewriting the section, providing additional examples or revised figures to assist visual learners, etc.
- In other cases, one or more of the SmartBook questions for a section was not as clear as it might be 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. 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.



Plants Contain Different Types of Photosynthetic Pigments

MAKING CONNECTIONS

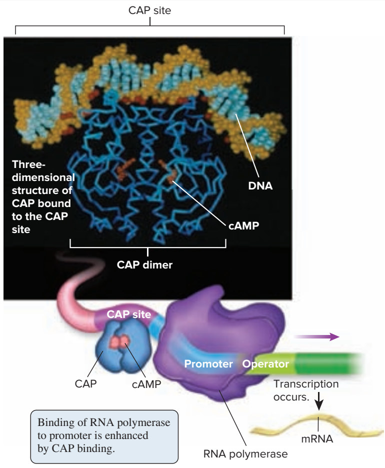


Figure 12.8 **Positive control of the *lac* operon by the catabolite activator protein (CAP).** When cAMP is bound to CAP, CAP binds to the DNA and causes it to bend. This bend facilitates the binding of RNA polymerase.
© Thomas Steitz, Howard Hughes Medical Institute, Yale University

BioConnections: *Refer back to Figure 8.13. What is the function of cAMP in eukaryotic cells?*

Biology Principle

The Genetic Material Provides a Blueprint for Reproduction

The covalent linkage of a sequence of bases allows DNA to store information.

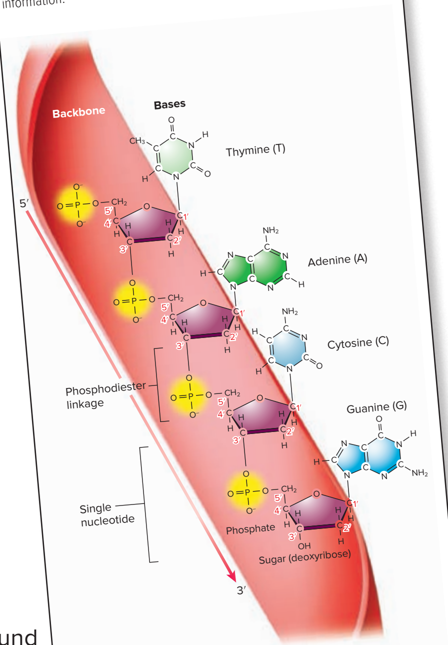


Figure 9.5 **The structure of a DNA strand.** Nucleotides are covalently bonded to each other in a linear manner. Notice the directionality of the strand and that it carries a particular sequence of bases. An RNA strand has a very similar structure, except the sugar is ribose rather than deoxyribose and uracil is substituted for thymine.

Principles of Biology are introduced in Chapter 1 and are then threaded throughout the entire textbook. This is achieved in two ways. First, the principles are highlighted in selected figures in which the specific principle is illustrated.

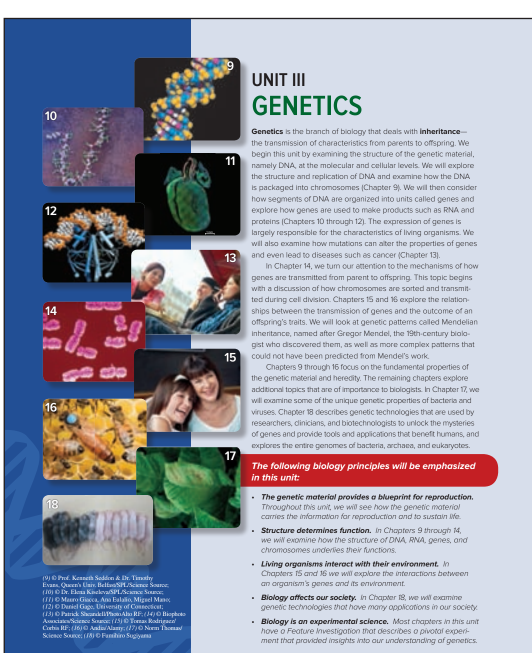
BioConnections BioConnections are questions found in selected figure legends in each chapter that help students make connections between biological concepts. BioConnections help students understand that their study of biology involves linking concepts together and building on previously learned information. Answers to the BioConnections are found in Appendix B.

In addition, a Conceptual Question at the end of each chapter is directly aimed at exploring a particular Biology Principle related to the content of the chapter.

Conceptual Questions

1. What is the difference between inducible and repressible operons?
2. Transcriptional regulation often involves a regulatory protein that binds to a segment of DNA and a small effector molecule that binds to the regulatory protein. Do the following terms apply to a regulatory protein, a segment of DNA, or a small effector molecule? (a) repressor, (b) inducer, (c) operator, (d) corepressor, (e) activator
3. **PRINCIPLES** A principle of biology is that the genetic material provides a blueprint for reproduction. Explain how gene regulation is an important mechanism for reproduction and sustaining life.

Unit openers serve two purposes. They allow the student to see the big picture of the unit. In addition, the unit openers draw attention to the principles of biology that will be emphasized in that unit.



The following biology principles will be emphasized in this unit:

- ***The genetic material provides a blueprint for reproduction.*** *Throughout this unit, we will see how the genetic material carries the information for reproduction and to sustain life.*
- ***Structure determines function.*** *In Chapters 9 through 14, we will examine how the structure of DNA, RNA, genes, and chromosomes underlies their functions.*
- ***Living organisms interact with their environment.*** *In Chapters 15 and 16 we will explore the interactions between an organism's genes and its environment.*
- ***Biology affects our society.*** *In Chapter 18, we will examine genetic technologies that have many applications in our society.*
- ***Biology is an experimental science.*** *Most chapters in this unit have a Feature Investigation that describes a pivotal experiment that provided insights into our understanding of genetics.*

Strengthen Problem Solving Skills and Key Concept Development with Connect®

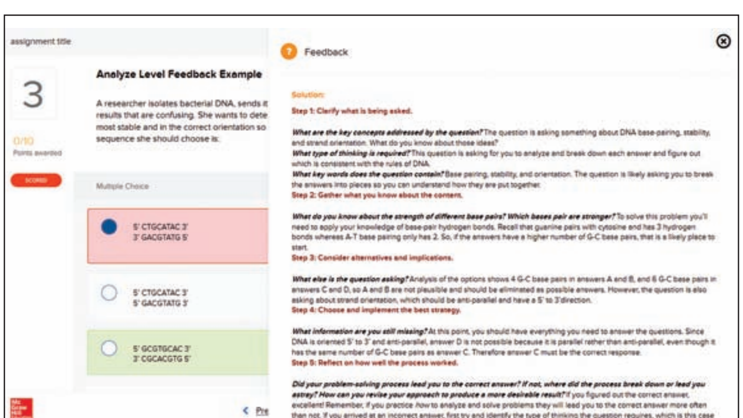
Problem Solving Skills

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 *Principles of Biology,* Second 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 their 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 Blooms questions in Connect are supported with hints, to help students focus on important information for answering the question. After submitting an answer, the student is given detailed feedback that walks through the problem solving process, using Socratic questions in a decision tree-style framework to scaffold learning. Each step models and reinforces the learning process.

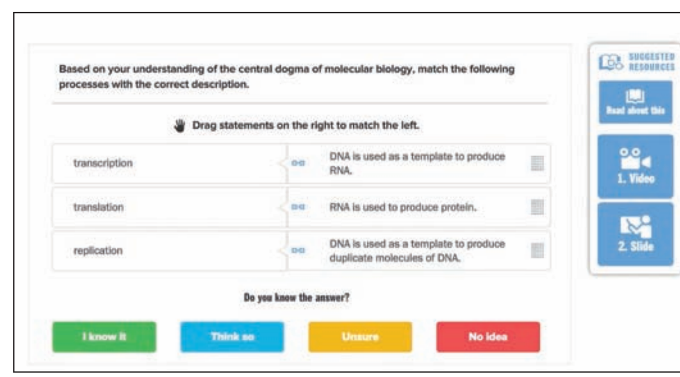
The feedback for each higher level Blooms question (Apply, Analyze, Evaluate) follows a similar process: Clarify Question, Gather Content, Choose Answer, Reflect on Process.

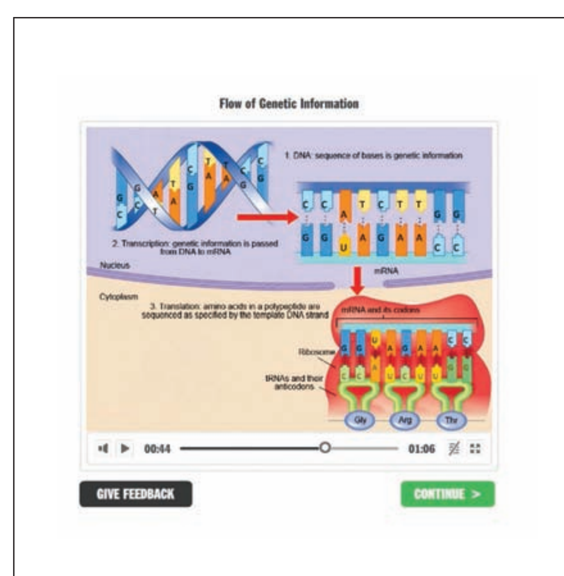


Key Concept Development

SmartBook with Learning Resources

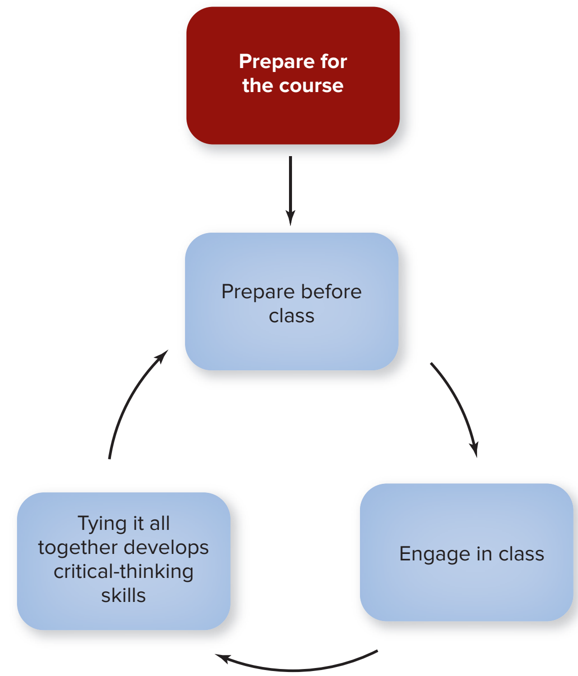
To help students understand key concepts, SmartBook® for *Principles of Biology,* Second Edition, is enhanced with Learning Resources. Based on student usage data, derived from thousands of SmartBook users of the first edition, concepts that proved more challenging for students are supported with Learning Resources to enhance the textbook presentation. Learning Resources, such as animations and tutorials, are indicated in Smartbook adjacent to the textbook content. If a student is struggling with a concept based on his/her performance of the SmartBook questions, the student is given an option to review the Learning Resource or the student can click on the Learning Resources at any time.





Using Connect® and *Principles of Biology*, Second Edition

Principles of Biology, Second Edition, and its online assets have been carefully crafted to help professors and students work efficiently and effectively through the material in the course, making the most of instructional and study time.



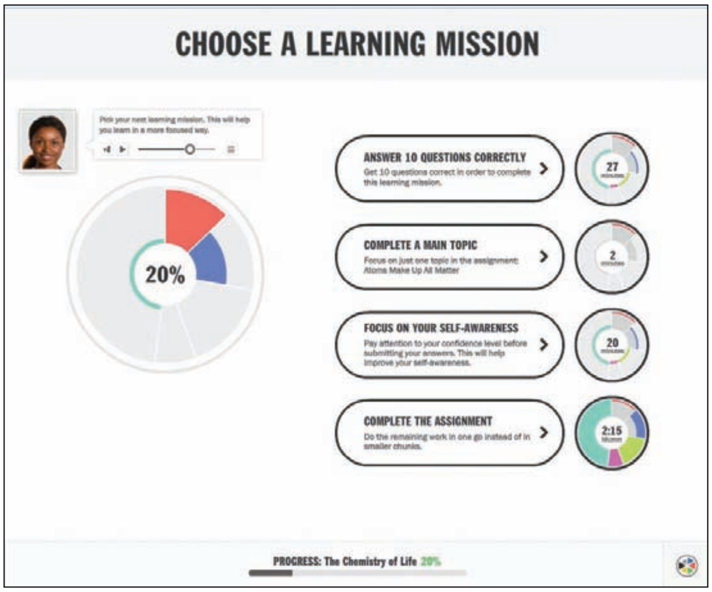
Prepare for the Course

Many biology students struggle the first few weeks of class. Many institutions expect students to start majors biology having a working knowledge of basic chemistry and cellular biology. *LearnSmart Prep* is now available in Connect. Professors can assign modules in LearnSmart Prep to help students get up to speed on core concepts, or students can access LearnSmart Prep directly through the LearnSmart Prep link.

LEARNSMART PREP®

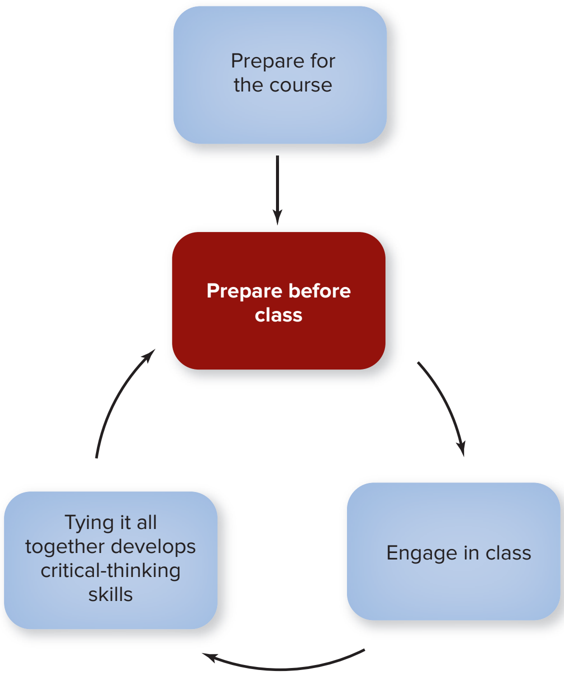
LearnSmart Prep is an adaptive learning tool designed to increase student success and aid retention through the first few weeks of class. Using this digital tool, majors biology students can master some of the most fundamental and challenging principles of biology before they begin to struggle in the first few weeks of class.

1. A diagnostic establishes your baseline comprehension and knowledge; then the program generates a learning plan tailored to your academic needs and schedule.



2. As you work through the learning plan, the program asks you questions and tracks your mastery of concepts. If you answer questions about a particular concept incorrectly, the program will provide a learning resource (ex. animation or tutorial) on that concept, then ensure that you understand the concept by asking you more questions. Didn't get it the first time? Don't worry—*LearnSmart Prep* will keep working with you!

3. Using *LearnSmart Prep*, you can identify the content you don't understand, focus your time on content you need to know but don't, and therefore improve your chances of success in your majors biology course.



Prepare Before Class

Students who are most successful in college are those who have developed effective study skills and who use those skills before, during, and after class.

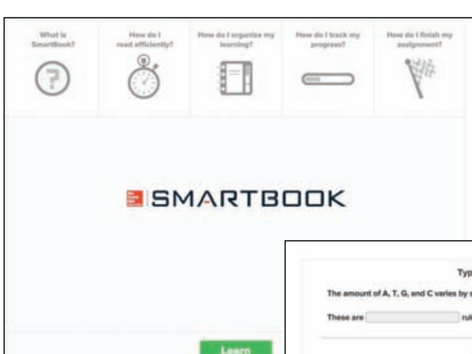
Students can maximize time in class by previewing the material before stepping into the lecture hall. *Principles of Biology*, Second Edition, is available in two formats: the printed text as well as the online SmartBook. Students can use either of these options to preview the material before lecture. Becoming familiar with terminology and basic concepts will allow students to follow along in class and engage in the content in a way that allows for better retention.

Professors can help students prepare for class by making preclass assignments. SmartBook assignments are effective for introducing terminology and general concepts.

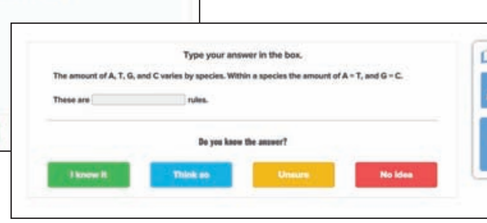
SmartBook provides a personalized, adaptive reading experience.

SMARTBOOK®

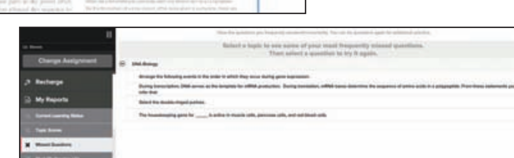
Powered by an intelligent diagnostic and adaptive engine, **SmartBook** facilitates the reading process by identifying what content a student knows and doesn't know through adaptive assessments.



◀ The SmartBook experience starts by previewing key concepts from the chapter and ensuring that you understand the big ideas.



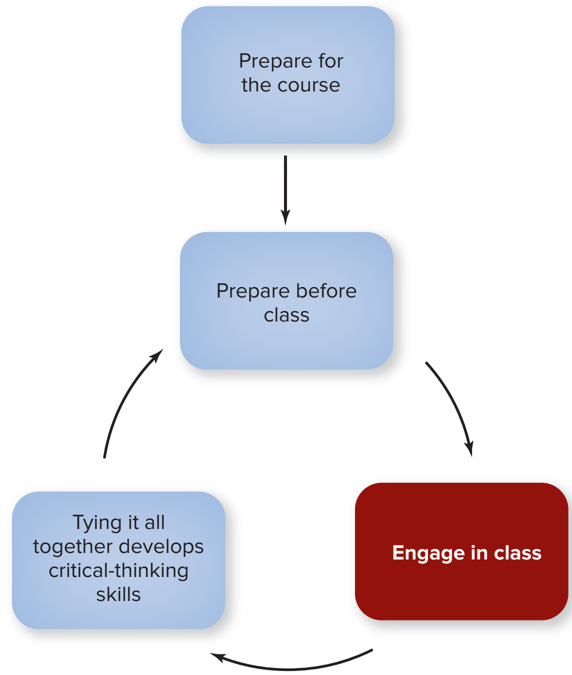
▲ SmartBook asks you questions that identify gaps in your knowledge. The reading experience then continuously adapts in response to the assessments—highlighting the material you need to review based on what you don't know.



▲ The reports in SmartBook help identify topics where you need more work.

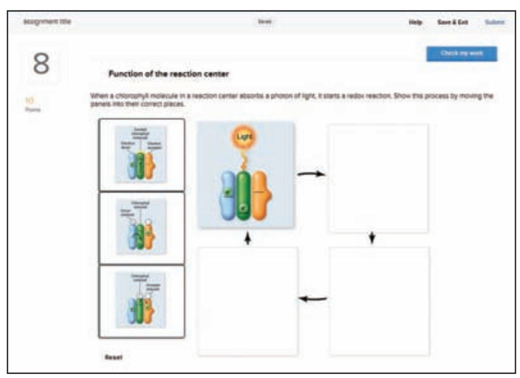
Engage in Class

McGraw-Hill Connect® provides online presentation, assignment, and assessment solutions. It connects students with the tools and resources they'll need to achieve success. A robust set of questions and activities is presented in the Question Bank and a separate set of questions to use for exams is presented in the Test Bank. Instructors can edit existing questions and author entirely new problems. They can track individual student performance—by question, assignment, or in relation to the class overall—with detailed grade reports.



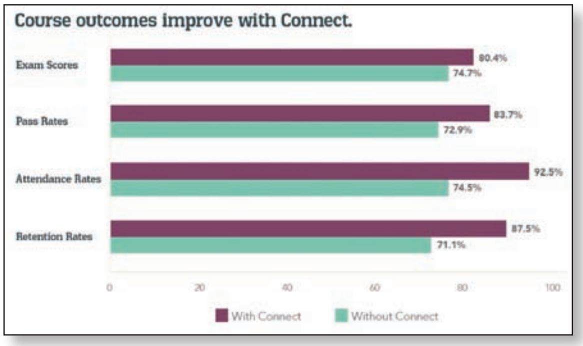
1 Preclass assignments to help students engage in the content during class.

Assignments are accessed through Connect and could include homework assignments, quizzes, SmartBook assignments, and other resources.

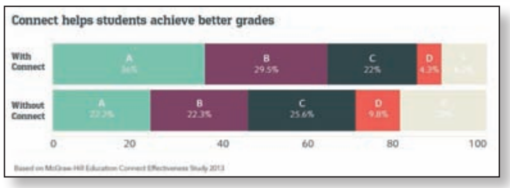


Interactive and traditional questions help assess students' knowledge of the material.

2 Connect Insight is Connect's visual analytics dashboard for instructors and students.



Provides at-a-glance student performance on assignments. Instructors can use the information for a just-in-time approach to teaching.

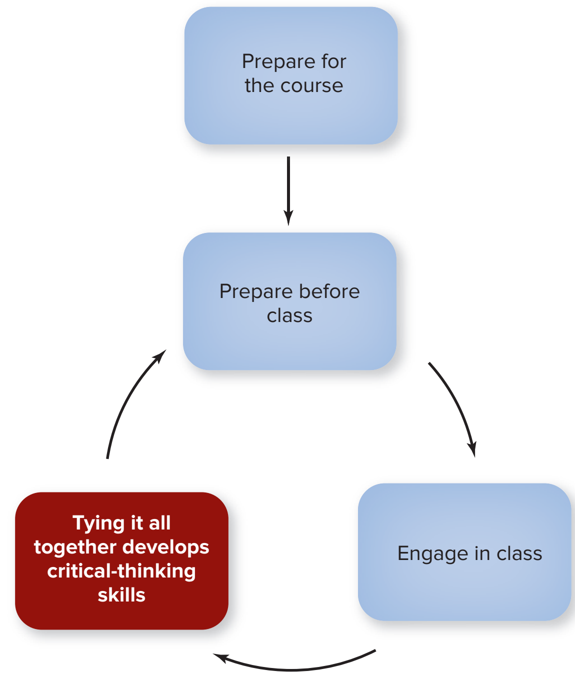


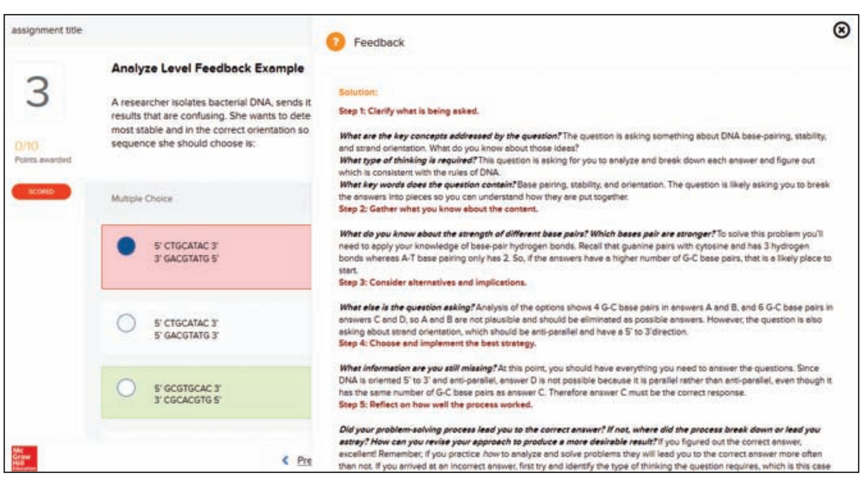
Presents data that empower students to improve performance that is efficient and effective.

Tying It All Together

Follow up class with assessment that helps students develop critical-thinking skills. Set up assignments from the various assessment banks in Connect.

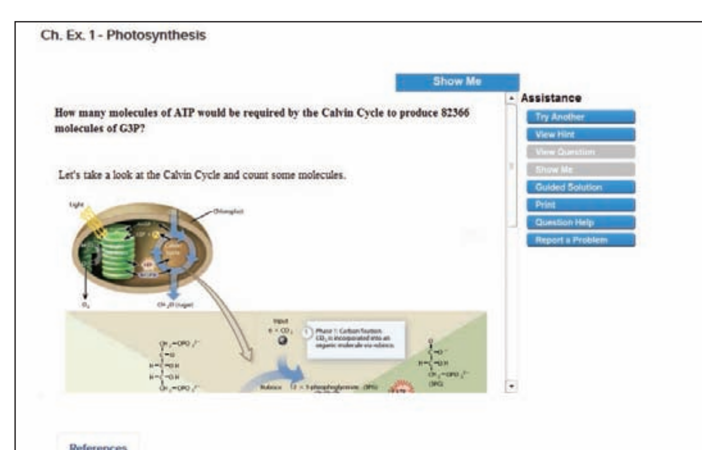
The Question and Test Banks contain higher order critical-thinking questions that require students to demonstrate a more in-depth understanding of the concepts—instructors can quickly and easily filter the banks for these questions using higher level Blooms tags.





Detailed Feedback All higher level Blooms questions that involve problem solving contain detailed feedback in Connect. The feedback walks students through the steps of the problem-solving process and helps them evaluate their scientific-thinking skills.

Many chapters also contain a **Quantitative Question Bank**. These are more challenging algorithmic questions, intended to help your students practice their quantitative reasoning skills. Hints and guided solution options step students through a problem.



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Required=Results

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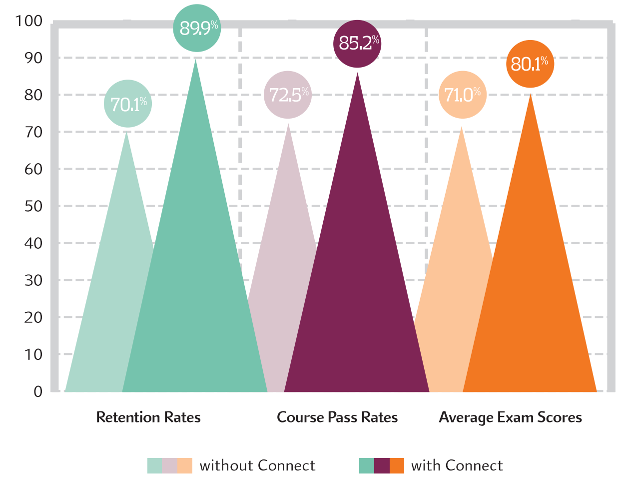
McGraw-Hill Connect®
Learn Without Limits

Connect is a teaching and learning platform that is proven to deliver better results for students and instructors.

Connect empowers students by continually adapting to deliver precisely what they need, when they need it, and how they need it, so your class time is more engaging and effective.

> 73% of instructors who use **Connect** require it; instructor satisfaction **increases** by 28% when **Connect** is required.

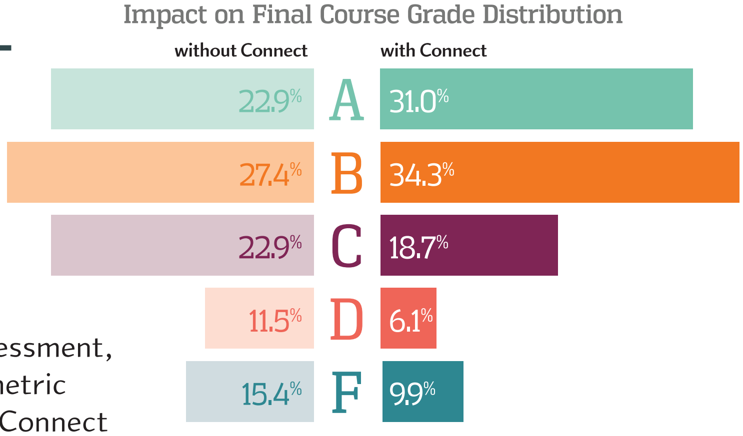
Connect's Impact on Retention Rates, Pass Rates, and Average Exam Scores



Using **Connect** improves retention rates by **19.8%**, passing rates by **12.7%**, and exam scores by **9.1%.**

Analytics

Impact on Final Course Grade Distribution



Connect Insight®

Connect Insight is Connect's new one-of-a-kind visual analytics dashboard—now available for both instructors and students—that provides at-a-glance information regarding student performance, which is immediately actionable. By presenting assignment, assessment, and topical performance results together with a time metric that is easily visible for aggregate or individual results, Connect Insight gives the user the ability to take a just-in-time approach to teaching and learning, which was never before available. Connect Insight presents data that empowers students and helps instructors improve class performance in a way that is efficient and effective.

> Students can view their results for any **Connect** course.

Mobile

Connect's new, intuitive mobile interface gives students and instructors flexible and convenient, anytime–anywhere access to all components of the Connect platform.

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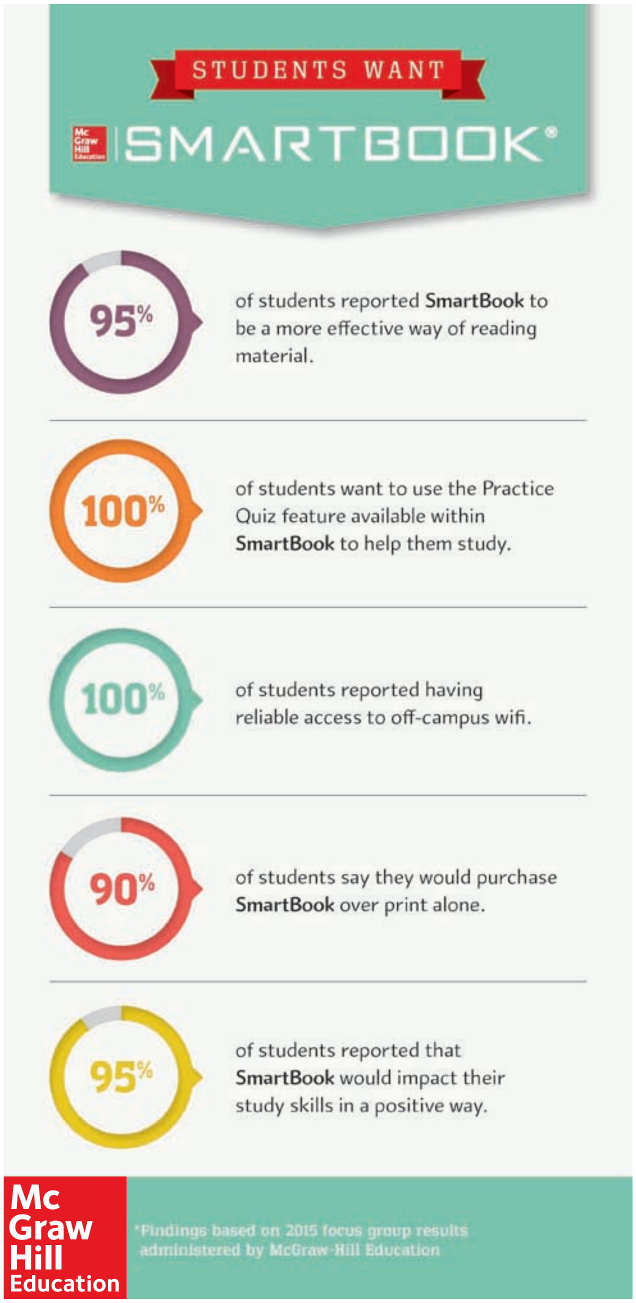

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Acknowledgments

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 that help the authors modify the content of their book so it is logical, easy to read, and inspiring. The editorial team for *Principles of Biology*, Second Edition, has been a catalyst that kept this project rolling. The members played various roles in the editorial process. Justin Wyatt, Brand Manager for Majors Biology, did an outstanding job of overseeing the development of this new text. Elizabeth Sievers, Lead 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, Deb DeBord, for keeping our grammar on track.

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 near each other or if a figure is too large or too small. We are indebted to the tireless efforts of Jayne Klein, Content Project Manager, and David Hash, Senior Designer, at McGraw-Hill Education. Likewise, our production company, MPS Limited, did an excellent job with the paging and art revisions.

We would like to acknowledge the ongoing efforts of the superb marketing staff at McGraw-Hill Education. Special thanks to Patrick Reidy, Executive Marketing Manager, Life Sciences, for his ideas and enthusiasm for this book.

Other staff members at McGraw-Hill Education have ensured that the authors and editors were provided with adequate resources to achieve the goal of producing a superior textbook. These include Scott Virkler, Senior Vice President, Products & Markets; Marty Lange, Vice President, General Manager, Products & Markets; Lynn Breithaupt, Managing Director for Life Science.

We would like to thank the digital authors and subject matter experts who helped in the development of the digital assets in Connect that support *Principles of Biology*, Second Edition. Ian Quitadamo, Central Washington University, serves as the Lead Digital Author for Majors Biology, directing the development plan for the digital content. Cynthia Dadmun serves as the Lead for the Connect digital content team, and Johnny El-Rady, University of South Florida, serves as the Lead for the SmartBook development team.

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

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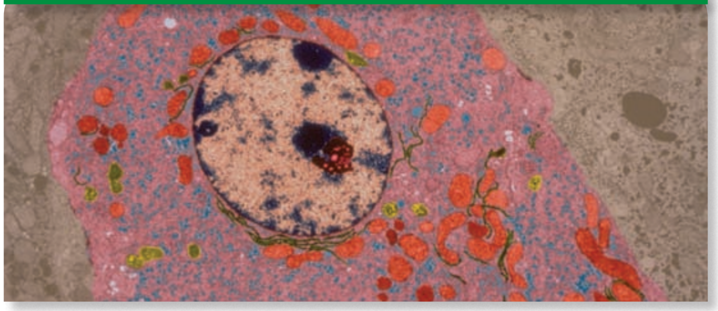

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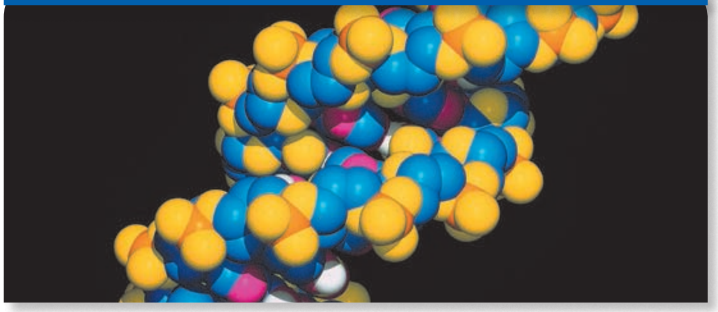

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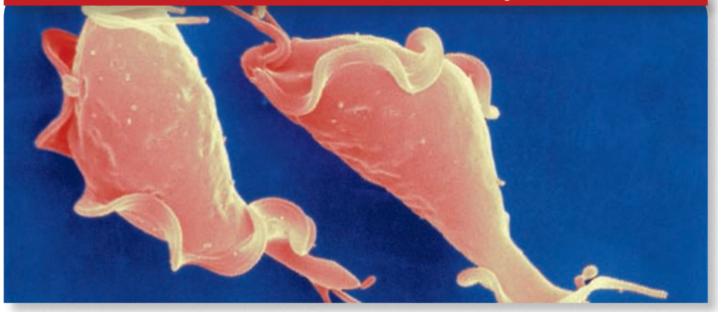

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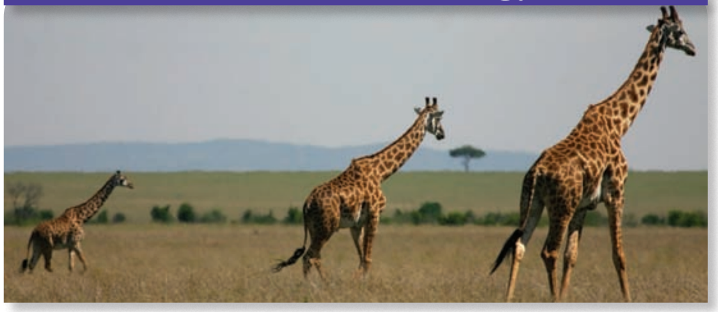

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An Introduction to Biology

1

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The polar bear (*Ursus maritimus*). The polar bear exhibits many characteristics that are adaptations to living in the cold Arctic climate and hunting seals.

Chapter Outline

1.1 Principles of Biology and the Levels of Biological Organization

1.2 Unity and Diversity of Life

1.3 Biology as a Scientific Discipline

Assess and Discuss

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 with far-reaching benefits. Certain ancient civilizations, such as the Greeks, Romans, and Egyptians, discovered that the bark of the white willow tree (*Salix alba*) could be used to fight fever. Chemists determined that willow bark contains a substance called salicylic acid, which led to the development of the related compound acetylsalicylic acid, more commonly known as aspirin (Figure 1.1). Today, aspirin is not only taken for fever and pain relief but is also recommended for the prevention of heart attacks and strokes.

As a more recent example, researchers determined that the venom from certain poisonous snakes contains a chemical that lowers blood pressure in humans. By analyzing that chemical, scientists have developed drugs called ACE inhibitors that treat high blood pressure (Figure 1.2).

These are just a couple 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 an exciting challenge 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 goal 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 our survey of biology by examining the basic principles that underlie the characteristics of all living organisms. We then take a deeper look at the process of evolution and how it explains the unity and diversity that we observe among living and extinct species. Finally, we will explore the general approaches that scientists follow when making new discoveries.

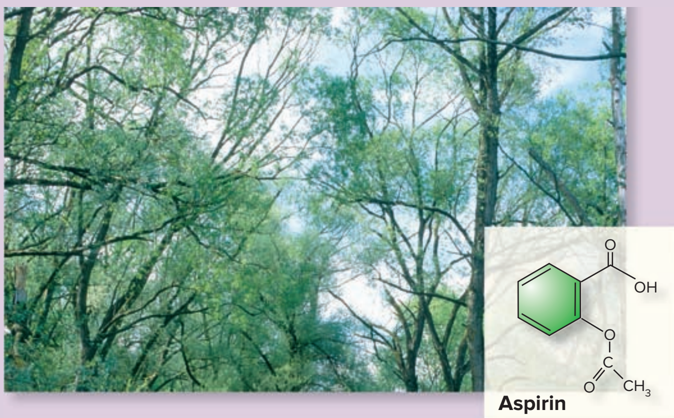


Figure 1.1 The white willow (*Salix alba*) and aspirin. Modern aspirin, acetylsalicylic acid, was developed after analysis of a chemical found in the bark of the white willow tree.

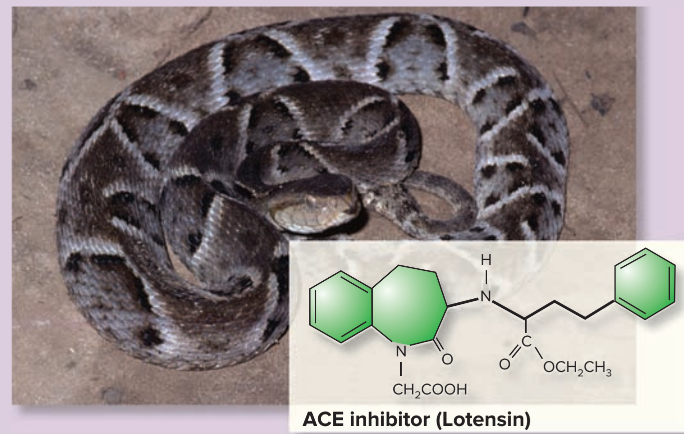


Figure 1.2 The Brazilian arrowhead viper and inhibitors of high blood pressure. Originally found in the venom of the Brazilian arrowhead viper (*Bothrops jararaca/jararacussa*), angiotensin-converting enzyme (ACE) inhibitors, including benazepril (Lotensin, chemical structure shown here), are commonly used to treat high blood pressure.

1.1 Principles of Biology and the Levels of Biological Organization

Learning Outcomes

1. Describe the principles of biology.
2. Explain how life can be viewed at different levels of biological complexity.

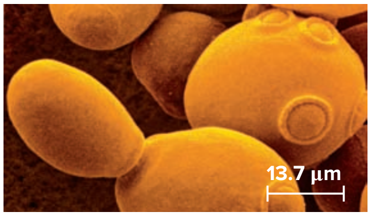
Because biology is the study of life, a good way to begin a biology textbook is to distinguish living organisms from nonliving objects. At first, the distinction might seem obvious. A person is alive, but a rock is not. However, the distinction between living and nonliving may seem less obvious when we consider microscopic entities. Is a bacterium alive? What about a virus or a chromosome? In this section, we will examine the principles that underlie the characteristics of all forms of life and explore other broad principles in biology. We will then consider the levels of organization that biologists study, ranging from atoms and small molecules to very large geographical areas.

The Study of Life Has Revealed a Set of Unifying Principles

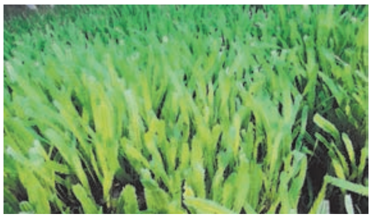
In the course of studying a vast number of species, biologists have learned that a set of principles applies to all fields of biology. Twelve broad principles are described in Figure 1.3. The first eight principles are often used as criteria for defining the basic features of life. You will see these 12 principles at many points as you progress through this textbook. In particular, we will draw your attention to them at the beginning of each unit, and we will refer to them within particular figures in Chapters 2 through 47. It should be noted that the principles of biology are also governed by the laws of chemistry and physics, which are discussed in Chapters 2, 3, and 6.

Principle 1: Cells are the simplest units of life. The term **organism** can be applied to all living things. Organisms maintain an internal order that is separated from the environment (Figure 1.3a). The simplest unit of such organization is the cell, which we will examine in Unit II. One of the foundations of biology is the **cell theory,** which states that (1) all organisms are composed of one or more cells, (2) cells are the smallest units of life, and (3) new cells come from pre-existing cells by cell division. Unicellular organisms are composed of one cell, whereas multicellular organisms such as plants and animals contain many cells. In plants and animals, each cell has an internal order, and the cells within the organism have specific arrangements and functions.

Principle 2: Living organisms use energy. The maintenance of organization requires energy. Therefore, all living organisms acquire energy from the environment and use that energy to maintain their internal order. Cells carry out a variety of chemical reactions that are responsible for the breakdown of energy-yielding nutrients. Such



(a) Cells are the simplest units of life:
Organisms maintain an internal order. The simplest unit of organization is the cell. Yeast cells are shown here.



(b) Living organisms use energy:
Organisms need energy to maintain internal order. These algae harness light energy via photosynthesis. Energy is used in chemical reactions collectively known as metabolism.

(c) Living organisms interact with their environment:
Organisms respond to environmental changes. These plants are growing toward the light.

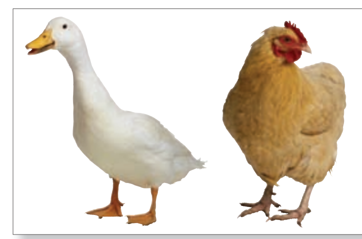
(d) Living organisms maintain homeostasis:
Organisms regulate their cells and bodies, maintaining relatively stable internal conditions, a process called homeostasis. For example, this bird maintains its internal body temperature on a cold day.

(e) Living organisms grow and develop:
Growth produces more or larger cells, whereas development produces organisms with a defined set of characteristics.

(f) The genetic material provides a blueprint for reproduction:
To sustain life over many generations, organisms must reproduce. Due to the transmission of genetic material, offspring tend to have traits like their parents.

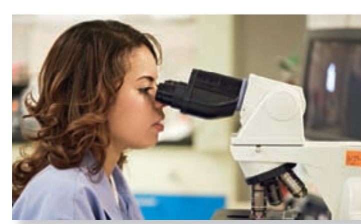
(g) Populations of organisms evolve from one generation to the next:
Populations of organisms change over the course of many generations. Evolution results in traits that promote survival and reproductive success.

(h) All species (past and present) are related by an evolutionary history:
The three mammal species shown here share a common ancestor, which was also a mammal.

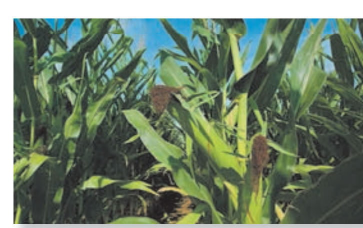


(i) Structure determines function:
In the example seen here, webbed feet (on ducks) function as paddles for swimming. Nonwebbed feet (on chickens) function better for walking on the ground.

(j) New properties of life emerge from complex interactions:
Our ability to see is an emergent property due to interactions among many types of cells in the eye and neurons that send signals to the brain.



(k) Biology is an experimental science:
The discoveries of biology are made via experimentation, which leads to theories and biological principles.



(l) Biology affects our society:
Many discoveries in biology have had major effects on our society. For example, biologists developed Bt-corn, which is resistant to insect pests and is widely planted by farmers.

Figure 1.3 **Twelve principles of biology.** The first eight principles are often used as criteria for defining the basic features of life. Note: The 12 principles described here were modeled after the themes and core competencies described in *Vision and Change in Undergraduate Biology,* a report that was published in 2009 and organized by the American Association for the Advancement of Science. *Vision and Change* proposed five themes. We have divided them into 10 principles to make them more accessible to beginning biology students. The five *Vision and Change* themes are related to our principles in the following manner: (1) evolution (principles g and h); (2) structure and function (principle i); (3) information flow, exchange, and storage (principles e and f); (4) pathways and transformations of energy and matter (principles b, c, and d); (5) systems (principles a and j). The last two principles are modeled after two core competencies described in *Vision and Change*: ability to apply the process of science (principle k) and ability to understand the relationship between science and society (principle l).

BioConnections: *Look ahead to Figure 4.15. Which of these principles is this figure emphasizing?*

reactions often release energy in a process called **cellular respiration.** The energy may be used to synthesize the components that make up individual cells and living organisms. Chemical reactions involved with the breakdown and synthesis of cellular molecules are collectively known as **metabolism.** Plants, algae, and certain bacteria directly harness light energy to produce their own nutrients in the process of **photosynthesis** (Figure 1.3b). They are the primary producers of food on Earth. In contrast, some organisms, such as animals and fungi, are consumers—they must use other organisms as food to obtain energy.

Principle 3: Living organisms interact with their environment. To survive, living organisms must interact with their environment, which includes other organisms they may encounter. All organisms must respond to environmental changes. In the winter, many species of mammals develop a thicker coat of fur that protects them from the cold temperatures. Plants respond to changes in the angle of the Sun. If you place a plant in a window, it will grow toward the light (Figure 1.3c).

Principle 4: Living organisms maintain homeostasis. Although life is a dynamic process, living cells and organisms regulate their cells and bodies to maintain relatively stable internal conditions, a process called **homeostasis** (from the Greek, meaning to stay the same). The degree to which homeostasis is achieved varies among different organisms. For example, most mammals and birds maintain a relatively stable body temperature in spite of changing environmental temperatures (Figure 1.3d), whereas reptiles and amphibians tolerate a wider fluctuation in body temperature. By comparison, all organisms continually regulate their cellular metabolism so that nutrient molecules are used at an appropriate rate and new cellular components are synthesized when they are needed.

Principle 5: Living organisms grow and develop. All living organisms grow and develop. **Growth** produces more or larger cells, which usually results in an increase in size and weight. Multicellular organisms, such as plants and animals, begin life at a single-cell stage (for example, a fertilized egg) and then undergo multiple cell divisions to develop into a complete organism with many cells. Among unicellular organisms such as bacteria, new cells are relatively small, and they increase in volume by the synthesis of additional cellular components. **Development** is a series of changes in the state of a cell, a tissue, an organ, or an organism, eventually resulting in organisms with a defined set of characteristics (Figure 1.3e).

Principle 6: The genetic material provides a blueprint for reproduction. All living organisms have a finite life span. To sustain life, organisms must **reproduce,** or generate offspring (Figure 1.3f). A key feature of reproduction is that offspring tend to have characteristics that greatly resemble those of their parent(s). How is this possible? All living organisms contain genetic material composed of **deoxyribonucleic acid (DNA),** which 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) that 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 are largely responsible for the traits of living organisms.

Principle 7: Populations of organisms evolve from one generation to the next. The first six characteristics of life, which we have just considered, apply to individual organisms over the short run. Over the long run, another universal characteristic of life is **biological evolution,** or simply **evolution,** which 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 (Figure 1.3g). 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.

In many chapters of this textbook, you will find a subsection called Evolutionary Connections, which focuses on the evolutionary aspects of the chapter's material.

Principle 8: All species (past and present) are related by an evolutionary history. Principle 7 considers evolution as an ongoing process that happens from one generation to the next. Evidence from a variety of sources, including the fossil record and DNA sequences, also indicates that all organisms on Earth share a common ancestry. For example, the three species of mammals shown in Figure 1.3h shared a common ancestor in the past, which was also a mammal. We will discuss evolutionary relationships further in Section 1.2.

Principle 9: Structure determines function. In addition to the preceding eight characteristics of life, biologists have identified other principles that are important in all fields of biology. The principle that structure determines function pertains to very tiny biological molecules as well as very large biological structures. For example, at the microscopic level, a cellular protein called actin naturally assembles into structures that are long filaments. The function of these filaments is to provide support and shape to cells. At the macroscopic level, let's consider the feet of different birds (Figure 1.3i). 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. In this case, the structure of a bird's feet, webbed versus nonwebbed, is a critical feature that affects their function.

Principle 10: New properties of life emerge from complex interactions. In biology, when individual components in 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 (Figure 1.3j). Our ability to see is an emergent property of this complex arrangement of different cell types.

Principle 11: Biology is as an experimental science. Biology is an inquiry process. Biologists are curious about the characteristics of living organisms and ask questions about those characteristics. For example, a cell biologist may wonder why a cell produces a specific protein when it is confronted with high temperature. An ecologist may ask herself why a particular bird eats insects in the summer and seeds in the winter. To answer such questions, biologists typically gather additional information and ultimately form a hypothesis, which is a proposed explanation for a natural phenomenon. The next stage is to design one or more experiments to test the validity of a hypothesis (Figure 1.3k).

Like evolution, experimentation is such a key aspect of biology that many chapters of this textbook include a Feature Investigation—an actual research study that showcases the experimental approach.

Principle 12: Biology affects our society. The influence of biology is not confined to textbooks and classrooms. The work of biologists has far-reaching effects in our society. For example, biologists have discovered drugs that are used to treat many different human diseases. Likewise, biologists have created technologies that have many uses. Examples include the use of microorganisms to make medical products, such as human insulin, and the genetic engineering of crops to make them resistant to particular types of insect pests (Figure 1.3l).

Living Organisms Are Studied at Different Levels of Organization

The organization of living organisms can be analyzed at different levels of biological complexity, starting with the smallest level of organization and progressing to levels that are physically much larger and more complex. **Figure 1.4** depicts a scientist'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.** Many smaller molecules bonded together to form a large polymer is called a **macromolecule.** Carbohydrates, proteins, and nucleic acids (DNA and RNA) are important macromolecules found in living organisms.
3. **Cells:** Molecules and macromolecules associate with each other to form larger structures such as cells. A **cell** is surrounded by a membrane and contains a variety of molecules and macromolecules. As noted earlier, a cell is the simplest unit of life.
4. **Tissues:** In the case of multicellular organisms such as plants and animals, 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 tissue, including muscle, nervous, and connective tissue.
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 that live in the same environment. 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 between a community of organisms and its physical environment. Unit VIII considers biology 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.

1.1 Reviewing the Concepts

- Biology is the study of life. Discoveries in biology help us understand how life exists, and they have many practical applications, such as the development of drugs to treat human diseases (Figures 1.1, 1.2).
- Eight principles underlie the characteristics that are common to all forms of life. All living things (1) are composed of cells as their simplest unit; (2) use energy; (3) interact with their environment; (4) maintain homeostasis; (5) grow and develop; and (6) have genetic material for reproduction. Also, (7) populations of organisms evolve from one generation to the next and (8) are connected by an evolutionary history (Figure 1.3).
- Additional important principles of biology are that (9) structure determines function; (10) new properties emerge from complex interactions; (11) biology is an experimental science; and (12) biology influences our society.
- Living organisms can be viewed at different levels of biological organization: atoms, molecules and macromolecules, cells, tissues, organs, organisms, populations, communities, ecosystems, and the biosphere (Figure 1.4).

1.1 Testing Your Knowledge

1. The wing of a bird, the wing of an insect, and the wing of a bat have similar shapes. Which principle of biology does this observation pertain to?
   a. Living organisms use energy.
   b. Living organisms maintain homeostasis.
   c. Structure determines function.
   d. Populations of organisms evolve from one generation to the next.
   e. All of the above are correct.

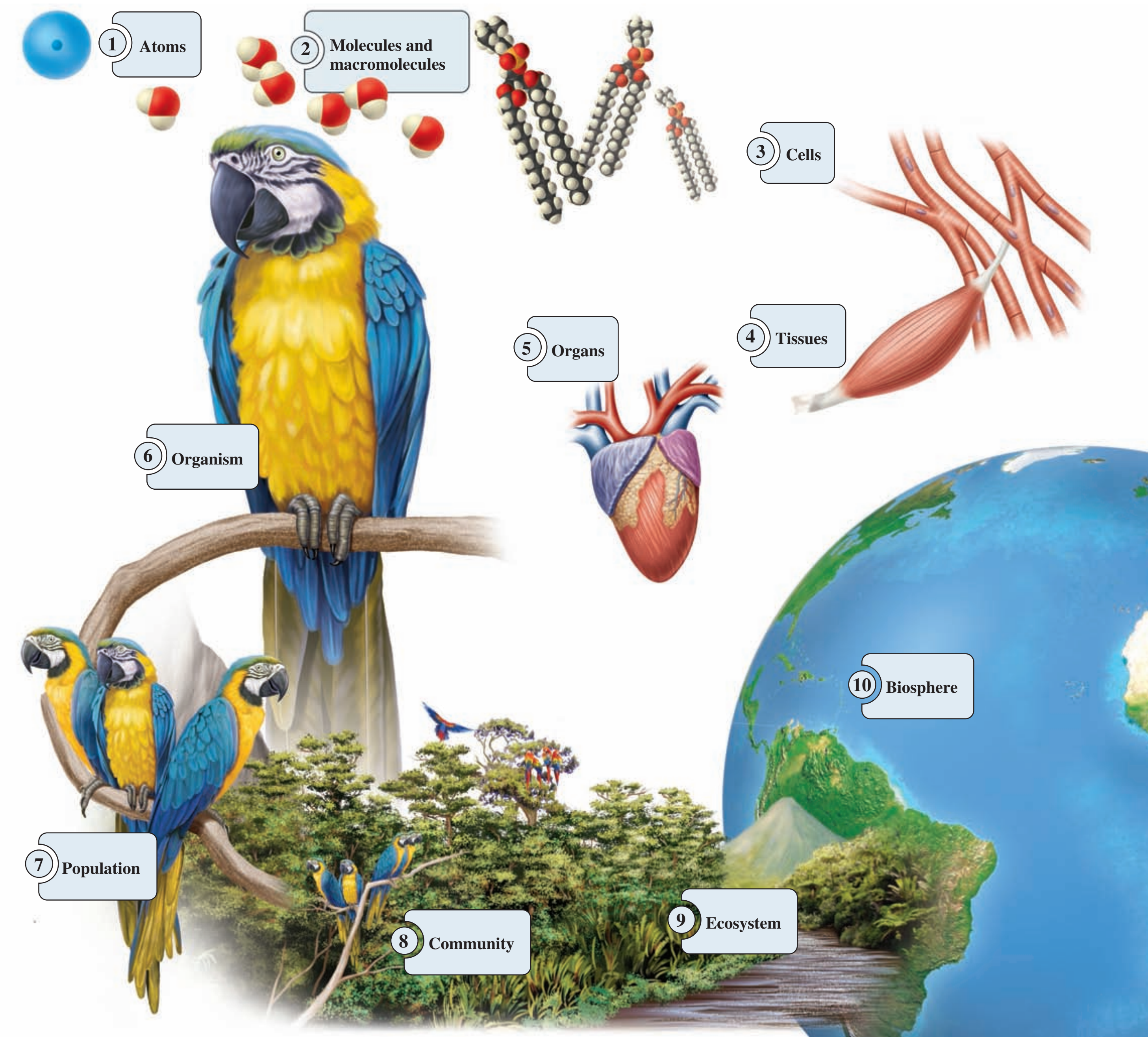


Figure 1.4 The levels of biological organization.

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

2. Which of the following is the most complex level of biological organization?
   a. organism **b.** tissue **c.** community **d.** population

1.2 Unity and Diversity of Life

Learning Outcomes

1. Explain the two basic mechanisms by which evolutionary change occurs: vertical descent with mutation and horizontal gene transfer.
2. Outline how organisms are classified (taxonomy).
3. Describe how evolution accounts for unity and diversity in biology.

Unity and diversity are two words that often are used to describe the living world. As we have seen, 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. Life on Earth is united by an evolutionary past in which modern organisms have evolved from populations of pre-existing organisms.

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, from hot and dry deserts to 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 section, we will begin to examine the unity and diversity that exist 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 an organism's structure and function, because evolutionary change involves modifications of characteristics in pre-existing populations. Over long periods of time, populations may change so that structures with a particular function may 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**).

Evolutionary change occurs by two mechanisms: vertical descent with mutation and horizontal gene transfer. Let's take a brief look at each of these mechanisms.

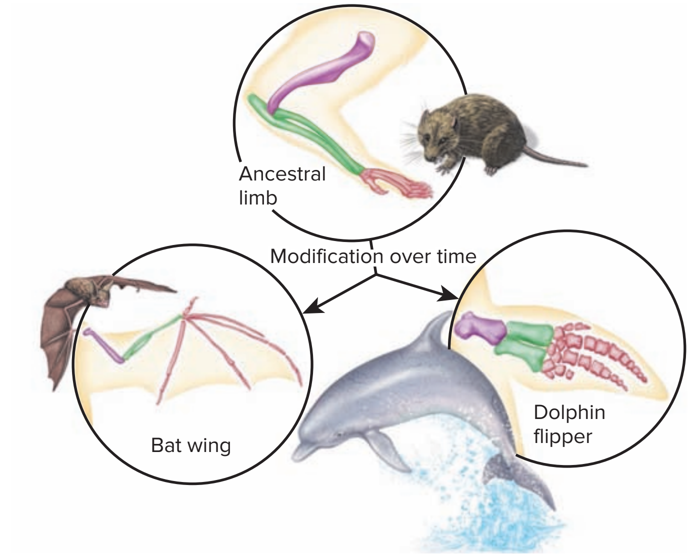


Figure 1.5 An example showing a modification that has occurred as a result of biological evolution. The wing of a bat and the flipper of a dolphin are modifications of a limb that was used for walking in a pre-existing ancestor.

Concept Check: *Among mammals, give two examples of how the tail has been modified and has different purposes.*

Vertical Descent with Mutation

The traditional way to study evolution is to examine a progression of changes in a series of ancestors. Such a series is called a **lineage.** Biologists have traditionally depicted such evolutionary change in a diagram like the one shown in **Figure 1.6**, which shows a portion of the lineage that gave rise to modern horses. In this mechanism of evolution, called **vertical evolution,** new species evolve from pre-existing ones by the accumulation of **mutations,** which are heritable changes in the genetic material of organisms. 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, horse 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. Horses with genetic variation that made them larger were more likely to escape predators and 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 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 Chapter 21, genes are sometimes transferred between organisms by **horizontal gene transfer**—a process in which an organism incorporates genetic material from another organism without being the offspring of that organism. 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. This can occur by the transfer of an antibiotic resistance gene from one bacterial species to another via horizontal gene transfer.

Traditionally, biologists have described evolution using diagrams such as that in Figure 1.6, which depict the vertical evolution of species over a long timescale. In this view, all living organisms evolved from a common ancestor, resulting in a "tree of life" that could describe the 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 concept of evolution as it occurs over time. Rather than a tree of life, a more appropriate way to view the unity of living organisms is to describe it as a "web of life" (as discussed in Chapter 21; look ahead to Figure 21.12), which accounts for both vertical evolution and horizontal gene transfer.

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

As biologists 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 categorization is usually based

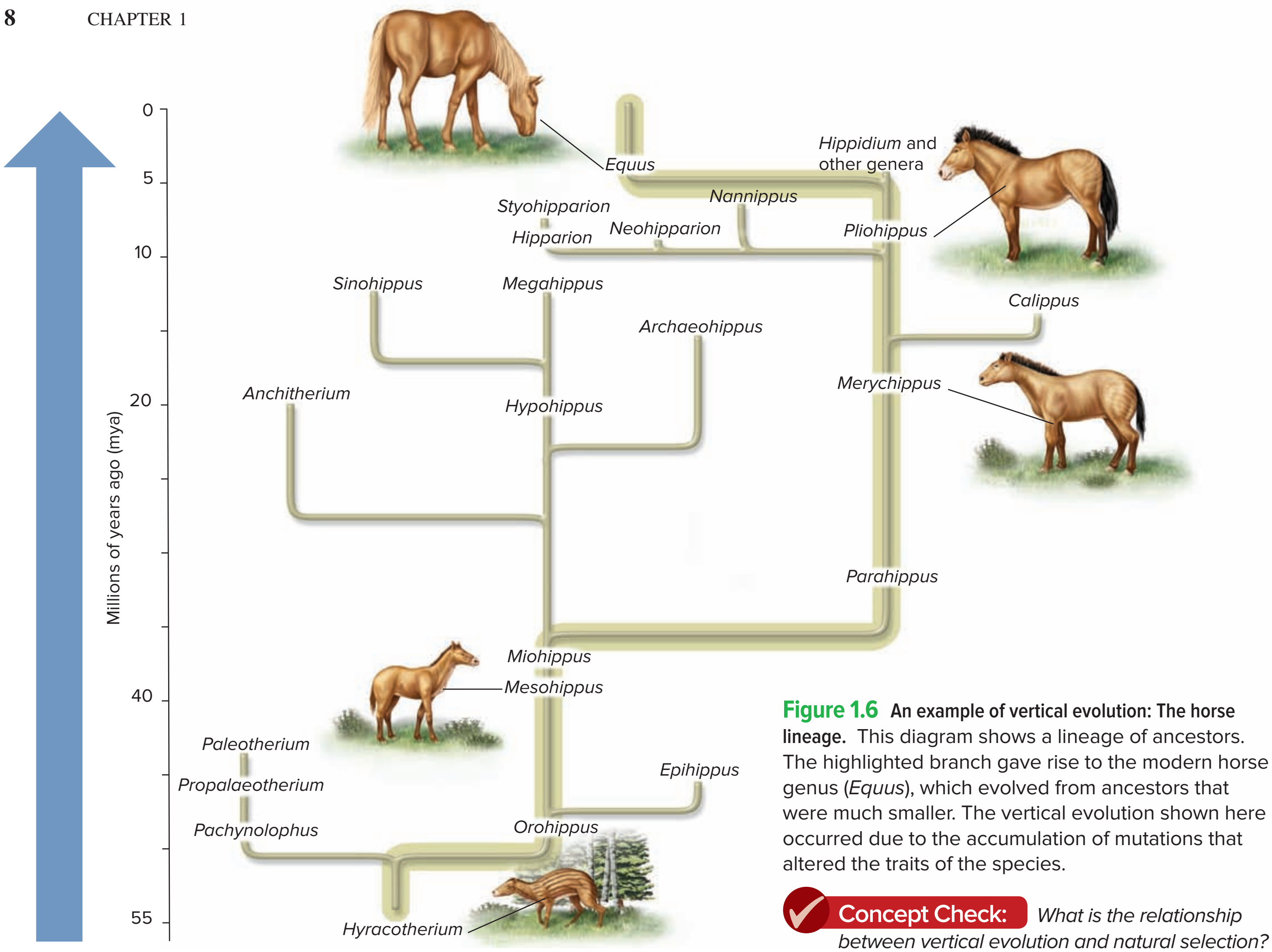


Figure 1.6 **An example of vertical evolution: The horse lineage.** This diagram shows a lineage of ancestors. The highlighted branch gave rise to the modern horse genus (*Equus*), which evolved from ancestors that were much smaller. The vertical evolution shown here occurred due to the accumulation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

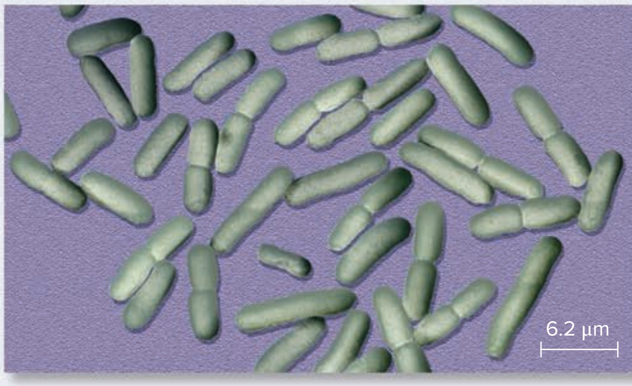
Concept Check: *What is the relationship between vertical evolution and natural selection?*

on vertical evolution. 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 grouping of species is termed **taxonomy.**

Let's first consider taxonomy on a broad scale. From an evolutionary perspective, all forms of life can be placed into three large categories, or **domains,** called **Bacteria, Archaea,** and **Eukarya** (**Figure 1.7**). 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 domain Eukarya are termed **eukaryotic;** they have larger cells with internal compartments that serve various functions. A defining distinction between prokaryotic and eukaryotic cells is that eukaryotic cells have a **nucleus** in which the genetic material is surrounded by a membrane. The organisms in domain Eukarya are divided into seven broad categories called **supergroups.**

Taxonomy involves multiple levels in which particular species are placed into progressively smaller and smaller groups of organisms that are more closely related to each other evolutionarily. Such an approach emphasizes the unity and diversity of different species. As an example, let's consider clownfish, which are found in the Indian and Pacific Oceans and are popular among saltwater aquarium enthusiasts (**Figure 1.8**). Several species of clownfish have been identified.

One species of clownfish, which is orange with white stripes, has several common names, including Ocellaris clownfish. The broadest grouping for this clownfish is the domain, Eukarya, followed by progressively smaller divisions, from supergroup (Opisthokonta) to kingdom (Animalia) and eventually to species. In the animal kingdom, clownfish are part of a phylum, Chordata, the chordates, which is subdivided into classes. Clownfish are in a class called Actinopterygii, which includes all ray-finned fishes. The common ancestor that gave rise to ray-finned fishes arose about 420 million years ago (mya). Actinopterygii is subdivided into several smaller orders. The clownfish are in the order Perciformes (bony fish). The order is, in turn, divided into families; the clownfish belong to the family of marine fish called Pomacentridae, which are often brightly colored. Families are divided into genera (singular, genus). The genus *Amphiprion* is composed of 28 different species; these are various types of clownfish. Therefore, the genus contains species that are very similar to each other in form and have evolved from a common (extinct) ancestor that lived relatively recently on an evolutionary timescale.



(a) Domain Bacteria: Mostly unicellular prokaryotes that inhabit many diverse environments on Earth

(b) Domain Archaea: Unicellular prokaryotes that often live in extreme environments, such as hot springs

Protists: Mostly unicellular and some multicellular organisms that are now subdivided into seven broad groups based on their evolutionary relationships

Plants: Multicellular organisms that can carry out photosynthesis

Fungi: Unicellular and multicellular organisms that have a cell wall but cannot carry out photosynthesis; fungi usually survive on decaying organic material

Animals: Multicellular organisms that usually have a nervous system and are capable of locomotion; they must eat other organisms or the products of other organisms to live

(c) Domain Eukarya: Unicellular and multicellular organisms having cells with internal compartments that serve various functions

Figure 1.7 **The three domains of life.** **(a)** Bacteria and **(b)** Archaea are domains consisting of prokaryotic cells. The third domain, **(c)** Eukarya, comprises species that are eukaryotes.

(a) © BSIP/agefotostock RF; *(b)* © Eye of Science/Science Source; *(c Protists)* © Jan Hinsch/Getty Images; *(c Plants)* © Kent Foster/Science Source; *(c Fungi)* © Carl Schmidt-Luchs/SPL/Science Source; *(c Animals)* © Ingram Publishing/agefotostock RF

BioConnections: *Look ahead to Figure 21.1. Are fungi more closely related to plants or animals?*