CAMPBELL

BIOLOGY IN FOCUS

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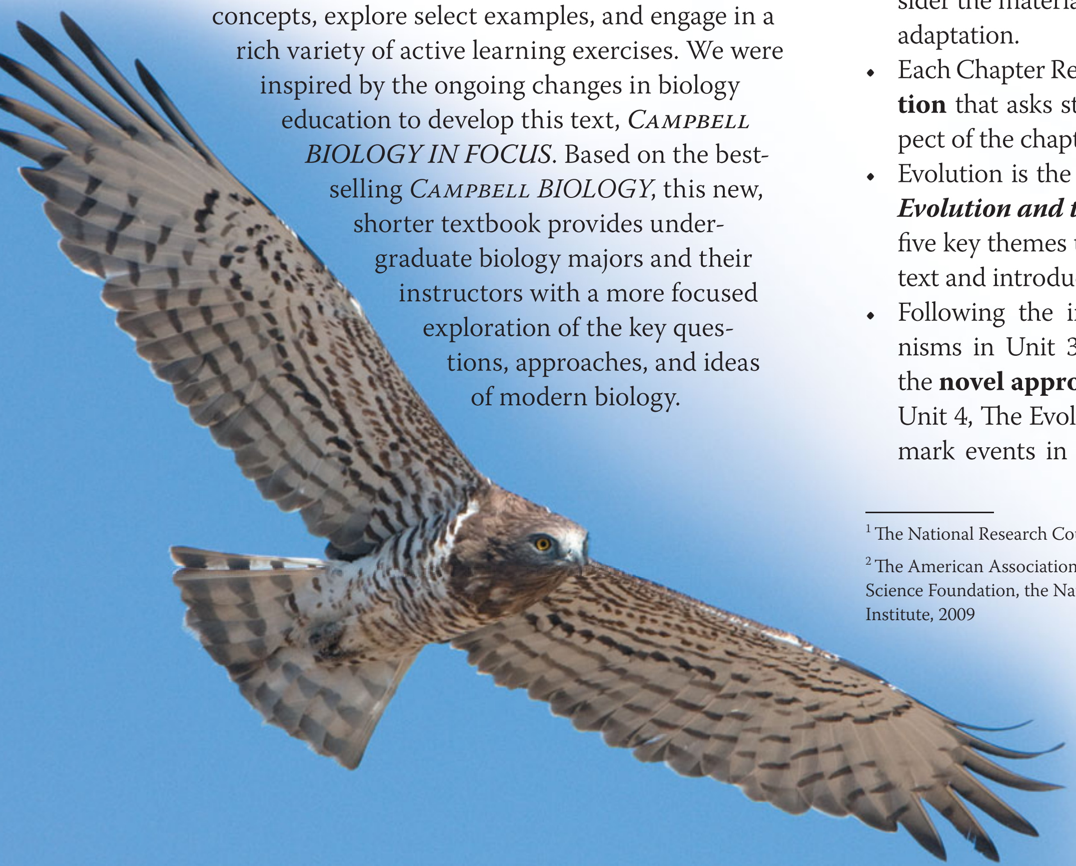
Preface

The short-toed snake eagle (*Circaetus gallicus*) that gazes from the cover of this book has an eye much like our own, yet evolutionary forces have honed its ability to spot a snake from a quarter mile up in the air. The eagle's keen eye is a metaphor for our goal in writing this text: to focus with high intensity on the core concepts that biology majors need to master in the introductory biology course. The current explosion of biological information, while exhilarating in its scope, poses a significant challenge—how best to teach a subject that is constantly expanding its own boundaries. In particular, instructors have become increasingly concerned that their students are overwhelmed by a growing volume of detail and are losing sight of the important ideas in biology.

In response to this challenge, groups of biologists have initiated efforts to refine and in some cases redesign the introductory biology course, summarizing their findings in reports that include *Bio 2010: Transforming Undergraduate Education for Future Research Biologists*[1] and *Vision and Change in Undergraduate Biology Education.*[2] Clear recommendations emerging from these initiatives are to focus course material and instruction on key ideas while transforming the classroom through active learning and scientific inquiry. Many instructors have embraced such approaches and changed how they teach. Cutting back on the amount of detail they present, they focus on core biological concepts, explore select examples, and engage in a rich variety of active learning exercises. We were inspired by the ongoing changes in biology education to develop this text, *Campbell Biology in Focus*. Based on the best-selling *Campbell Biology*, this new, shorter textbook provides undergraduate biology majors and their instructors with a more focused exploration of the key questions, approaches, and ideas of modern biology.



Our Guiding Principles

Our objective in creating *Campbell Biology in Focus* was to produce a shorter text by streamlining selected material, while emphasizing conceptual understanding and maintaining clarity, proper pacing, and rigor. Here, briefly, are the four guiding principles for our approach.

Focus on Core Concepts and Skills

We developed this text to help students master the fundamental content and scientific skills they need as college biology majors. In structuring the text, we were guided by discussions with many biology professors, analysis of hundreds of syllabi, study of the debates in the literature of scientific pedagogy, and our experience as instructors at a range of institutions. The result is a **briefer book for biology majors** that is designed to inform, engage, and inspire.

Evolution as the Foundation of Biology

Evolution is the central theme of all biology, and it is the core theme of this text, as exemplified by the various ways that evolution is integrated into the text:

- Every chapter explicitly addresses the topic of evolution through an **Evolution section** that leads students to consider the material in the context of natural selection and adaptation.
- Each Chapter Review includes a **Focus on Evolution Question** that asks students to think critically about how an aspect of the chapter relates to evolution.
- Evolution is the unifying idea of **Chapter 1**, ***Introduction: Evolution and the Foundations of Biology***, which outlines five key themes that students will encounter throughout the text and introduces the process of scientific inquiry.
- Following the in-depth coverage of evolutionary mechanisms in Unit 3, evolution also provides the storyline for the **novel approach to presenting biological diversity** in Unit 4, The Evolutionary History of Life. Focusing on landmark events in the history of life, the text highlights how

[1] The National Research Council of the National Academies, 2003

[2] The American Association for the Advancement of Science, supported by the National Science Foundation, the National Institutes of Health, and Howard Hughes Medical Institute, 2009

key adaptations arose within groups of organisms and how evolutionary events led to the diversity of life on Earth today.

Engaging Students in Scientific Thinking

Helping students learn to "think like a scientist" is a nearly universal goal of introductory biology courses. Students need to understand how to formulate and test hypotheses, design experiments, and interpret data. Scientific thinking and data interpretation skills top lists of learning outcomes and foundational skills desired for students entering higher-level courses. *CAMPBELL BIOLOGY IN FOCUS* meets this need in several ways:

- **Scientific Skills Exercises** in every chapter use real data to build skills in graphing, interpreting data, designing experiments, and working with math—skills essential for students to succeed in biology. These exercises can also be assigned and automatically graded in MasteringBiology.
- **Scientific Inquiry Questions** in the end-of-chapter material give students further practice in scientific thinking.
- **Inquiry Figures** and **Research Method Figures** reveal *how* we know *what* we know and model the process of scientific inquiry.

Outstanding Pedagogy

Since the publication of the first edition in 1987, *CAMPBELL BIOLOGY* has been praised for its clear and engaging narrative, superior pedagogy, and innovative use of art to promote student learning. These hallmark values are also at the core of *CAMPBELL BIOLOGY IN FOCUS*:

- In each chapter, a framework of carefully selected **Key Concepts** helps students distinguish the "forest" from the "trees."
- Questions throughout the text catalyze learning by encouraging students to **actively engage with and synthesize key material**:
    - To counter students' tendencies to compartmentalize information, **Make Connections Questions** ask students to connect what they are learning in a particular chapter to material covered in other chapters or units.
    - **Figure Legend Questions** foster student interaction with the figures.
    - Tiered **Concept Check Questions** test comprehension, require application, and prompt synthesis.
    - **Draw It Exercises** encourage students to test their understanding of biology through drawing.
    - **Summary of Key Concepts Questions** make reading the summary an active learning experience.

Our overall aim is to help students see biology as a whole, with each chapter adding to the network of knowledge they are building. To support this goal further, each unit in *CAMPBELL BIOLOGY IN FOCUS* opens with a **visual preview** that tells the story of the chapters' contents, showing how the material in the unit fits into a larger context.

Organization of the Text

CAMPBELL BIOLOGY IN FOCUS is organized into an introductory chapter and seven units that cover thoughtfully paced core concepts. In the course of streamlining this material, we have worked diligently to maintain the finely tuned coverage of fundamental concepts found in *CAMPBELL BIOLOGY*. As we developed this alternative text, we carefully considered each chapter of *CAMPBELL BIOLOGY*. Based on surveys and discussions with instructors and analyses of hundreds of syllabi and reviews, we made informed choices about how to design each chapter of *CAMPBELL BIOLOGY IN FOCUS* to meet the needs of instructors and students. In some chapters, we retained most of the material; in other chapters, we pruned material; and in still others, we completely reconfigured the material. We summarize the highlights here.

Chapter 1: Introduction: Evolution and the Foundations of Biology

Chapter 1 introduces the **five biological themes** woven throughout this text: the core theme of **Evolution**, together with **Organization**, **Information**, **Energy and Matter**, and **Interactions**. Chapter 1 also explores the process of scientific inquiry through a case study describing experiments on the evolution of coat color in the beach mouse. The chapter concludes with a discussion of the importance of diversity within the scientific community.

Unit 1: Chemistry and Cells

A succinct, two-chapter treatment of basic chemistry provides the foundation for this unit focused on cell structure and function. The related topics of cell membranes and cell signaling are consolidated into one chapter. Due to the importance of the fundamental concepts in Units 1 and 2, much of the material in the rest of these two units has been retained from *CAMPBELL BIOLOGY*.

Unit 2: Genetics

Topics in this unit include meiosis and classical genetics as well as the chromosomal and molecular basis for genetics and gene expression. We also include a chapter on the regulation of gene expression and one on the role of gene regulation in development, stem cells, and cancer. Methods in biotechnology are integrated into appropriate chapters. The stand-alone chapter on viruses can be taught at any point in the course. The final chapter in the unit, on genome evolution, provides both a capstone for the study of genetics and a bridge to the evolution unit.

Unit 3: Evolution

This unit provides in-depth coverage of essential evolutionary topics, such as mechanisms of natural selection, population genetics, and speciation. Early in the unit, Chapter 20 introduces "tree thinking" to support students in interpreting phylogenetic trees and thinking about the big picture of evolution. Chapter 23 focuses on mechanisms that have influenced long-term patterns of evolutionary change. Throughout the unit, new discoveries in fields ranging from paleontology to phylogenomics highlight the interdisciplinary nature of modern biology.

Unit 4: The Evolutionary History of Life

This unit employs a novel approach to studying the evolutionary history of biodiversity. Each chapter focuses on one or more major steps in the history of life, such as the origin of cells or the colonization of land. Likewise, the coverage of natural history and biological diversity emphasizes the evolutionary process—how factors such as the origin of key adaptations have influenced the rise and fall of different groups of organisms over time.

Unit 5: Plant Form and Function

The form and function of higher plants are often treated as separate topics, thereby making it difficult for students to make connections between the two. In Unit 5, plant anatomy (Chapter 28) and the acquisition and transport of resources (Chapter 29) are bridged by a discussion of how plant architecture influences resource acquisition. Chapter 30 provides a solid introduction to plant reproduction. It also explores crop domestication, examining controversies surrounding the genetic engineering of crop plants. The final chapter explores how environmental sensing and the integration of information by plant hormones influence plant growth and reproduction.

Unit 6: Animal Form and Function

A focused exploration of animal physiology and anatomy applies a comparative approach to a limited set of examples to bring out fundamental principles and conserved mechanisms. Students are first introduced to the closely related topics of homeostasis and endocrine signaling in an integrative introductory chapter. Additional melding of interconnected material is reflected in chapters that combine treatment of circulation and gas exchange, reproduction and development, neurons and nervous systems, and motor mechanisms and behavior.

Unit 7: Ecology

This unit applies the key themes of the text, including evolution, interactions, and energy and matter, to help students learn ecological principles. Chapter 40 integrates material on population growth and Earth's environment, highlighting the importance of both biological and physical processes in determining where species are found. Chapter 43 ends the book with a focus on global ecology and conservation biology. This chapter illustrates the threats to all species from increased human population growth and resource use. It begins with local factors that threaten individual species and ends with global factors that alter ecosystems, landscapes, and biomes.

MasteringBiology®

MasteringBiology is the most widely used online assessment and tutorial program for biology, providing an extensive library of homework assignments that are graded automatically. Self-paced tutorials provide individualized coaching with specific hints and feedback on the most difficult topics in the course. For example:

- The **Scientific Skills Exercises** from the text can be assigned and automatically graded in MasteringBiology.
- **Make Connections Tutorials** help students connect what they are learning in one chapter with material they have learned in another chapter.
- **Data Analysis Tutorials** allow students to analyze real data from online databases.
- **BioFlix® Tutorials** use 3-D movie-quality animations to help students master tough topics.

In addition, Reading Quiz questions, Student Misconception questions, and approximately 3,000 Test Bank questions are available for assignment.

MasteringBiology and the text work together to provide an unparalleled learning experience.

* * *

Our overall goal in developing this text was to assist instructors and students in their exploration of biology by emphasizing essential content and skills while maintaining rigor. Although this first edition is now completed, we recognize that *CAMPBELL BIOLOGY IN FOCUS*, like its subject, will evolve. As its authors, we are eager to hear your thoughts, questions, comments, and suggestions for improvement. We are counting on you—our teaching colleagues and all students using this book—to provide us with this feedback, and we encourage you to contact us directly by e-mail:

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About the Authors

The author team's contributions reflect their biological expertise as researchers and their teaching sensibilities gained from years of experience as instructors at diverse institutions. They are also experienced textbook authors, having written *Campbell Biology* in addition to *Campbell Biology in Focus*.

Lisa A. Urry

Lisa Urry (Chapter 1 and Units 1 and 2) is Professor of Biology and Chair of the Biology Department at Mills College in Oakland, California, and a Visiting Scholar at the University of California, Berkeley. After graduating from Tufts University with a double major in biology and French, Lisa completed her Ph.D. in molecular and developmental biology at Massachusetts Institute of Technology (MIT) in the MIT/Woods Hole Oceanographic Institution Joint Program. She has published a number of research papers, most of them focused on gene expression during embryonic and larval development in sea urchins. Lisa has taught a variety of courses, from introductory biology to developmental biology and senior seminar. As a part of her mission to increase understanding of evolution, Lisa also teaches a nonmajors course called Evolution for Future Presidents and is on the Teacher Advisory Board for the Understanding Evolution website developed by the University of California Museum of Paleontology. Lisa is also deeply committed to promoting opportunities for women and underrepresented minorities in science.

Michael L. Cain

Michael Cain (Chapter 1 and Units 3 and 4) is an ecologist and evolutionary biologist who is now writing full-time. Michael earned a joint degree in biology and math at Bowdoin College, an M.Sc. from Brown University, and a Ph.D. in ecology and evolutionary biology from Cornell University. As a faculty member at New Mexico State University and Rose-Hulman Institute of Technology, he taught a wide range of courses, including introductory biology, ecology, evolution, botany, and conservation biology. Michael is the author of dozens of scientific papers on topics that include foraging behavior in insects and plants, long-distance seed dispersal, and speciation in crickets. In addition to his work on *Campbell Biology in Focus*, Michael is also the lead author of an ecology textbook.

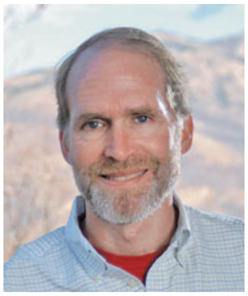
Steven A. Wasserman

Steve Wasserman (Chapter 1 and Unit 6) is Professor of Biology at the University of California, San Diego (UCSD). He earned his A.B. in biology from Harvard University and his Ph.D. in biological sciences from MIT. Through his research on regulatory pathway mechanisms in the fruit fly *Drosophila*, Steve has contributed to the fields of developmental biology, reproduction, and immunity. As a faculty member at the University of Texas Southwestern Medical Center and UCSD, he has taught genetics, development, and physiology to undergraduate, graduate, and medical students. He currently focuses on teaching introductory biology. He has also served as the research mentor for more than a dozen doctoral students and more than 50 aspiring scientists at the undergraduate and high school levels. Steve has been the recipient of distinguished scholar awards from both the Markey Charitable Trust and the David and Lucille Packard Foundation. In 2007, he received UCSD's Distinguished Teaching Award for undergraduate teaching.

Peter V. Minorsky

Peter Minorsky (Unit 5) is Professor of Biology at Mercy College in New York, where he teaches introductory biology, evolution, ecology, and botany. He received his A.B. in biology from Vassar College and his Ph.D. in plant physiology from Cornell University. He is also the science writer for the journal *Plant Physiology*. After a postdoctoral fellowship at the University of Wisconsin at Madison, Peter taught at Kenyon College, Union College, Western Connecticut State University, and Vassar College. His research interests concern how plants sense environmental change. Peter received the 2008 Award for Teaching Excellence at Mercy College.

Robert B. Jackson



Rob Jackson (Unit 7) is Professor of Biology and Nicholas Chair of Environmental Sciences at Duke University. Rob holds a B.S. in chemical engineering from Rice University, as well as M.S. degrees in ecology and statistics and a Ph.D. in ecology from Utah State University. Rob directed Duke's Program in Ecology for many years and just finished a term as the Vice President of Science for the Ecological Society of America. Rob has received numerous awards, including a Presidential Early Career Award in Science and Engineering from the National Science Foundation. He also enjoys popular writing, having published a trade book about the environment, *The Earth Remains Forever*, and two books of poetry for children, *Animal Mischief* and *Weekend Mischief*.

Jane B. Reece

The head of the author team for recent editions of *CAMPBELL BIOLOGY*, Jane Reece was Neil Campbell's longtime collaborator. Earlier, Jane taught biology at Middlesex County College and Queensborough Community College. She holds an A.B. in biology from Harvard University, an M.S. in microbiology from Rutgers University, and a Ph.D. in bacteriology from the University of California, Berkeley. Jane's research as a doctoral student and postdoctoral fellow focused on genetic recombination in bacteria. Besides her work on the Campbell textbooks for biology majors, she has been an author of *Campbell Biology: Concepts & Connections*, *Campbell Essential Biology*, and *The World of the Cell*.

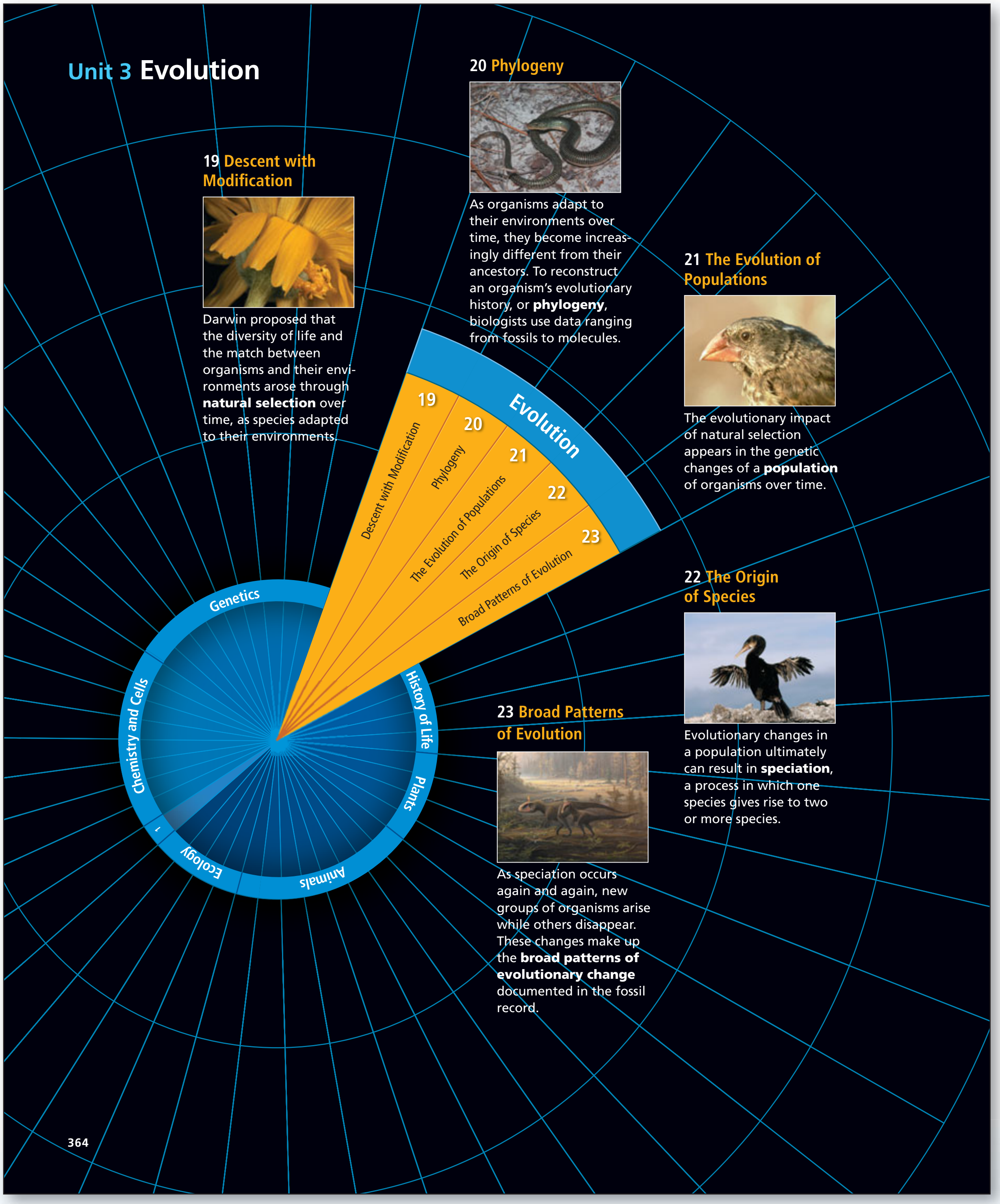
Neil A. Campbell

Neil Campbell (1946–2004) combined the investigative nature of a research scientist with the soul of an experienced and caring teacher. He earned his M.A. in zoology from the University of California, Los Angeles, and his Ph.D. in plant biology from the University of California, Riverside, where he received the Distinguished Alumnus Award in 2001. Neil published numerous research articles on desert and coastal plants and how the sensitive plant (*Mimosa*) and other legumes move their leaves. His 30 years of teaching in diverse environments included introductory biology courses at Cornell University, Pomona College, and San Bernardino Valley College, where he received the college's first Outstanding Professor Award in 1986. Neil was a visiting scholar in the Department of Botany and Plant Sciences at the University of California, Riverside.

Focus on the Big Picture

See the Story of the Unit

Each unit begins with a **visual preview** of the chapters' contents, showing how the material in the unit fits into a larger context.


Unit 3 Evolution

19 Descent with Modification

Darwin proposed that the diversity of life and the match between organisms and their environments arose through **natural selection** over time, as species adapted to their environments.

20 Phylogeny

As organisms adapt to their environments over time, they become increasingly different from their ancestors. To reconstruct an organism's evolutionary history, or **phylogeny**, biologists use data ranging from fossils to molecules.

21 The Evolution of Populations

The evolutionary impact of natural selection appears in the genetic changes of a **population** of organisms over time.

22 The Origin of Species

Evolutionary changes in a population ultimately can result in **speciation**, a process in which one species gives rise to two or more species.

23 Broad Patterns of Evolution

As speciation occurs again and again, new groups of organisms arise while others disappear. These changes make up the **broad patterns of evolutionary change** documented in the fossil record.

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Focus on the Key Concepts

Each chapter is organized around a framework of 3 to 6 **Key Concepts** that focus on the big picture and provide a context for the supporting details.

Students can get oriented by reading the **list of Key Concepts,** which introduces the big ideas covered in the chapter.

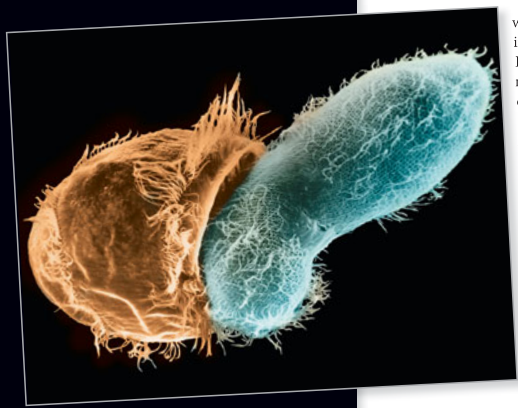
25

The Origin and Diversification of Eukaryotes

KEY CONCEPTS

25.1 Eukaryotes arose by endosymbiosis more than 1.8 billion years ago
25.2 Multicellularity has originated several times in eukaryotes
25.3 Four "supergroups" of eukaryotes have been proposed based on morphological and molecular data
25.4 Single-celled eukaryotes play key roles in ecological communities and affect human health

▼ **Figure 25.1** What enables the cell on the left to engulf its prey?



OVERVIEW

Shape Changers

The organisms in **Figure 25.1** are ciliates, a diverse group of single-celled eukaryotes named after the small appendages—cilia—that enable them to move. The ciliate on the left, *Didinium*, has begun a seemingly impossible task: it will engulf the *Paramecium* (right) in its entirety, even though the *Paramecium* is as large as it is.

Reflect for a moment on the magnitude of this feat. If we humans could do this, in a single swallow we could ingest more food than we would typically eat in a month. Like us, even the prokaryotes discussed in Chapter 24 cannot engulf food items their own size—although prokaryotes can metabolize an astonishing range of compounds, they can only absorb small particles of food. What enables *Didinium* to tackle food items that could easily evade a hungry prokaryote?

One key to *Didinium*'s success lies within its cells—it has a complex set of cytoskeletal proteins that enable the cell to change in shape dramatically as it feeds. *Didinium* also has small structures similar to miniature harpoons that it can eject to help ensnare its prey. These two features illustrate the structural complexity that characterizes the cells of *Didinium* and the other diverse, mostly unicellular groups of eukaryotes informally known as **protists**.

As we'll see, some protists change their form as they creep along using blob-like appendages, others are shaped like tiny trumpets, and still others resemble miniature jewelry. In this chapter, we'll explore how these shape-changing, structurally complex eukaryotic cells arose from their morphologically simpler prokaryotic ancestors. We'll also examine another major step in the evolutionary history of life: the origin of multicellular eukaryotes such as plants, fungi, and animals. Finally, we'll consider how single-celled eukaryotes affect ecosystems and human health.

Each **Key Concept** serves as the heading for a major section of the chapter.

CONCEPT 25.1

Eukaryotes arose by endosymbiosis more than 1.8 billion years ago

As we discussed in Chapter 24, all organisms were unicellular early in the history of life. The evolution of eukaryotes did not immediately change this, but it did involve fundamental changes in the structure of these individual cells. For

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After reading a concept section, students can check their understanding using the **Concept Check questions** on their own or in a study group.

Make Connections questions ask students to relate content in the chapter to a concept presented earlier in the course.

What If? questions ask students to apply what they've learned.

CONCEPT CHECK 25.2

1. Summarize the evidence that choanoflagellates are the sister group of animals.
2. **MAKE CONNECTIONS** Describe how the origin of multicellularity in animals illustrates Darwin's concept of descent with modification (see Concept 19.2).
3. **WHAT IF?** Cells in *Volvox*, plants, and fungi are similar in being enclosed by a cell wall. Predict whether the cell-to-cell attachments of these organisms form using similar or different molecules. Explain.

For suggested answers, see Appendix A.

Practice Scientific Skills

Scientific Skills Exercises in every chapter use real data to build key skills needed for biology, including data analysis, graphing, experimental design, and math skills.

Selected Scientific Skills Exercises include:

- Making a Line Graph and Calculating a Slope
- Interpreting Histograms
- Using the Chi-Square (χ^2) Test
- Analyzing DNA Deletion Experiments
- Making and Testing Predictions
- Interpreting Data in a Phylogenetic Tree
- Using the Hardy-Weinberg Equation to Interpret Data and Make Predictions
- Understanding Experimental Design and Interpreting Data
- Interpreting Data Values Expressed in Scientific Notation
- Designing an Experiment Using Genetic Mutants
- Interpreting a Graph with Log Scales
- Using the Logistic Equation to Model Population Growth

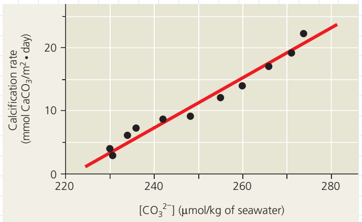
Scientific Skills Exercise

Interpreting a Scatter Plot with a Regression Line

How Does the Carbonate Ion Concentration of Seawater Affect the Calcification Rate of a Coral Reef? Scientists predict that acidification of the ocean due to higher levels of atmospheric CO_2 will lower the concentration of dissolved carbonate ions, which living corals use to build calcium carbonate reef structures. In this exercise, you will analyze data from a controlled experiment that examined the effect of carbonate ion concentration ($[CO_3^{2-}]$) on calcium carbonate deposition, a process called calcification.

How the Experiment Was Done The Biosphere 2 aquarium in Arizona contains a large coral reef system that behaves like a natural reef. For several years, a group of researchers measured the rate of calcification by the reef organisms and examined how the calcification rate changed with differing amounts of dissolved carbonate ions in the seawater.

Data from the Experiment The black data points in the graph below form a scatter plot. The red line, known as a linear regression line, is the best-fitting straight line for these points. These data are from one set of experiments, in which the pH, temperature, and calcium ion concentration of the seawater were held constant.



Interpret the Data

1. When presented with a graph of experimental data, the first step in analysis is to determine what each axis represents. (a) In words, explain what is being shown on the *x*-axis. Be sure to include the units. (b) What is being shown on the *y*-axis (including units)? (c) Which variable is the independent variable—the variable that was *manipulated* by the researchers? (d) Which variable is the dependent variable—the variable that responded to or depended on the treatment, which was *measured* by the researchers? (For additional information about graphs, see the Scientific Skills Review in Appendix F and in the Study Area in MasteringBiology.)
2. Based on the data shown in the graph, describe in words the relationship between carbonate ion concentration and calcification rate.
3. (a) If the seawater carbonate ion concentration is 270 µmol/kg, what is the approximate rate of calcification, and approximately how many days would it take 1 square meter of reef to accumulate 30 mmol of calcium carbonate ($CaCO_3$)? To determine the rate of calcification, draw a vertical line up from the *x*-axis at the value of 270 µmol/kg until it intersects the red line. Then draw a horizontal line from the intersection over to the *y*-axis to see what the calcification rate is at that carbonate ion concentration. (b) If the seawater carbonate ion concentration is 250 µmol/kg, what is the approximate rate of calcification, and approximately how many days would it take 1 square meter of reef to accumulate 30 mmol of calcium carbonate? (c) If carbonate ion concentration decreases, how does the calcification rate change, and how does that affect the time it takes coral to grow?
4. (a) Referring to the equations in Figure 2.24, determine which step of the process is measured in this experiment. (b) Do the results of this experiment support the hypothesis that increased atmospheric $[CO_2]$ will slow the growth of coral reefs? Why or why not?

Data from C. Langdon et al., Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef, *Global Biogeochemical Cycles* 14:639–654 (2000).

MB A version of this Scientific Skills Exercise can be assigned in MasteringBiology.

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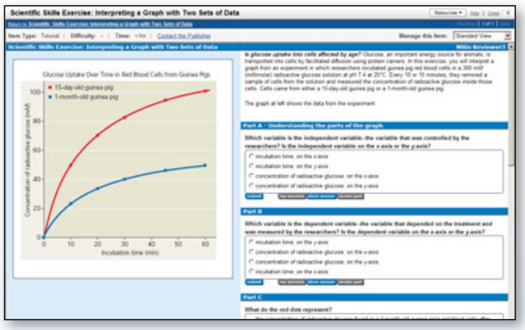
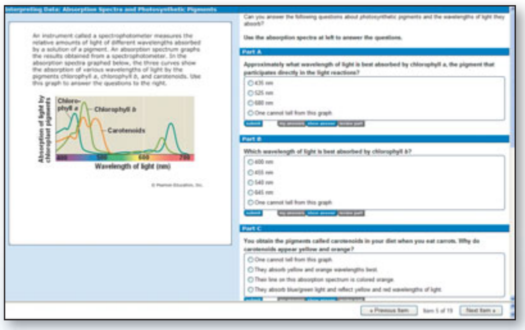


Scientific Skills Exercises from the text have assignable versions in MasteringBiology.



Interpreting Data Tutorials coach students on how to read and interpret data and graphs.

Engage in Scientific Thinking

Scientific Skills Exercise

Analyzing Polypeptide Sequence Data

Are Rhesus Monkeys or Gibbons More Closely Related to Humans? As discussed in Concept 3.6, DNA and polypeptide sequences from closely related species are more similar to each other than are sequences from more distantly related species. In this exercise, you will look at amino acid sequence data for the β polypeptide chain of hemoglobin, often called β-globin. You will then interpret the data to hypothesize whether the monkey or the gibbon is more closely related to humans.

How Such Experiments Are Done Researchers can isolate the polypeptide of interest from an organism and then determine the amino acid sequence. More frequently, the DNA of the relevant gene is sequenced, and the amino acid sequence of the polypeptide is deduced from the DNA sequence of its gene.

Data from the Experiments In the data below, the letters give the sequence of the 146 amino acids in β-globin from humans, rhesus monkeys, and gibbons. Because a complete sequence would not fit on one line here, the sequences are broken into three segments. Note that the sequences for the three different species are aligned so that you can compare them easily. For example, you can see that for all three species, the first amino acid is V (valine; see Figure 3.17) and the 146th amino acid is H (histidine).

Interpret the Data

1. Scan along the monkey and gibbon sequences, letter by letter, circling any amino acids that do not match the human sequence. (a) How many amino acids differ between the monkey and the human sequences? (b) Between the gibbon and human?
2. For each nonhuman species, what percent of its amino acids are identical to the human sequence of β-globin?
3. Based on these data alone, state a hypothesis for which of these two species is more closely related to humans. What is your reasoning?
4. What other evidence could you use to support your hypothesis?

Data from Human: http://www.ncbi.nlm.nih.gov/protein/AAA21113.1; rhesus monkey: http://www.ncbi.nlm.nih.gov/protein/122634; gibbon: http://www.ncbi.nlm.nih.gov/protein/122616

(MB) A version of this Scientific Skills Exercise can be assigned in MasteringBiology.

Species	Alignment of Amino Acid Sequences of β-globin
Human	1 VHLTPEEKSA VTALWGKVNV DEVGGEALGR LLVVYPWTQR FFESFGDLST PDAVMGNPKV
Monkey	1 VHLTPEEKNA VTTLWGKVNV DEVGGEALGR LLLVYPWTQR FFESFGDLSS PDAVMGNPKV
Gibbon	1 VHLTPEEKSA VTALWGKVNV DEVGGEALGR LLVVYPWTQR FFESFGDLST PDAVMGNPKV
Human	61 KAHGKKVLGA FSDGLAHLDN LKGTFATLSE LHCDKLHVDP ENFRLLGNVL VCVLAHHFGK
Monkey	61 KAHGKKVLGA FSDGLNHLDN LKGTFAQLSE LHCDKLHVDP ENFKLLGNVL VCVLAHHFGK
Gibbon	61 KAHGKKVLGA FSDGLAHLDN LKGTFAQLSE LHCDKLHVDP ENFRLLGNVL VCVLAHHFGK
Human	121 EFTPPVQAAY QKVVAGVANA LAHKYH
Monkey	121 EFTPQVQAAY QKVVAGVANA LAHKYH
Gibbon	121 EFTPQVQAAY QKVVAGVANA LAHKYH

▼ **Inquiry Figures** reveal "how we know what we know" by highlighting how researchers designed an experiment, interpreted their results, and drew conclusions.

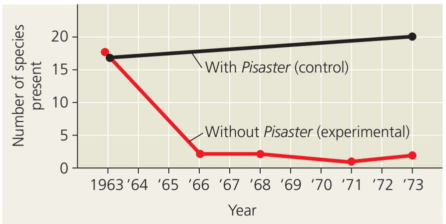
▼ Figure 41.15 Inquiry

Is *Pisaster ochraceus* a keystone predator?

Experiment In rocky intertidal communities of western North America, the relatively uncommon sea star *Pisaster ochraceus* preys on mussels such as *Mytilus californianus*, a dominant species and strong competitor for space.

Robert Paine, of the University of Washington, removed *Pisaster* from an area in the intertidal zone and examined the effect on species richness.

Results In the absence of *Pisaster*, species richness declined as mussels monopolized the rock face and eliminated most other invertebrates and algae. In a control area where *Pisaster* was not removed, species richness changed very little.



Conclusion *Pisaster* acts as a keystone species, exerting an influence on the community that is not reflected in its abundance.

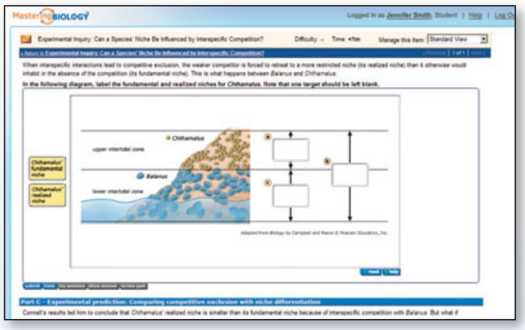
Source R. T. Paine, Food web complexity and species diversity, *American Naturalist* 100:65–75 (1966).

WHAT IF? Suppose that an invasive fungus killed most individuals of *Mytilus* at these sites. Predict how species richness would be affected if *Pisaster* were then removed.

After exploring the featured experiment, students test their analytical skills by answering the **What If? question**. ▶

Experimental Inquiry Tutorials, based on some of biology's most influential experiments, give students practice analyzing experimental design and data and help students understand how to reach conclusions based on collected data. Topics include:

- What Can You Learn About the Process of Science from Investigating a Cricket's Chirp?
- Which Wavelengths of Light Drive Photosynthesis?
- Does DNA Replication Follow the Conservative, Semiconservative, or Dispersive Model?
- Did Natural Selection of Ground Finches Occur When the Environment Changed?
- What Factors Influence the Loss of Nutrients from a Forest Ecosystem?

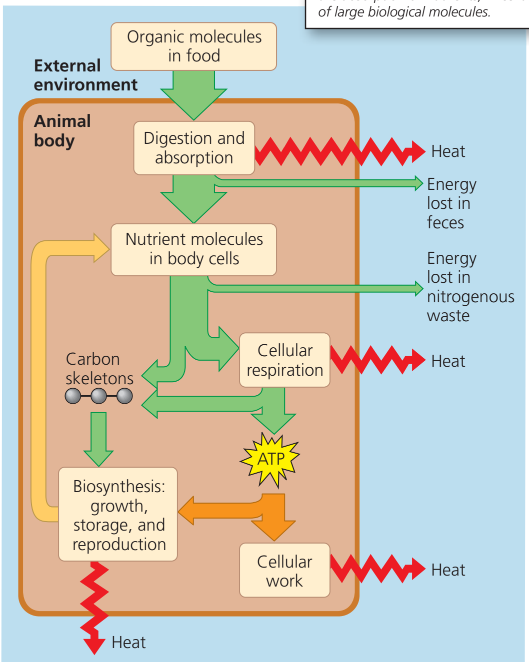


Synthesize and Assess

Make Connections Across Biology

By relating the content of a chapter to material presented earlier in the course, **Make Connections questions** help students develop a deeper understanding of biological principles.

MAKE CONNECTIONS *Review the idea of energy coupling (see Concept 6.3). Then use that idea to explain why heat is produced in the absorption of nutrients, in cellular respiration, and in the synthesis of large biological molecules.*



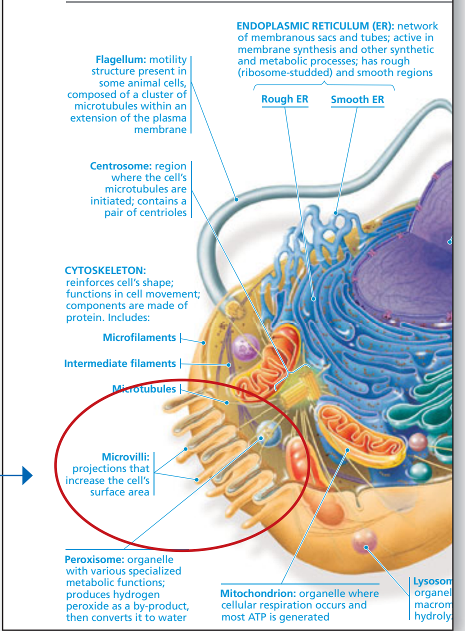
▲ **Figure 33.18 Bioenergetics of an animal: an overview.**

CONCEPT CHECK 28.3

1. Contrast primary growth in roots and shoots.
2. **WHAT IF?** If a plant species has vertically oriented leaves, would you expect its mesophyll to be divided into spongy and palisade layers? Explain.
3. **MAKE CONNECTIONS** How are root hairs and microvilli analogous structures? (See Figure 4.7 and the discussion of analogy in Concept 20.2.)

▼ **Figure 4.7** **Exploring Eukaryotic Cells**

Animal Cell (cutaway view of generalized cell)



Make Connections Tutorials help students connect biological concepts across chapters in an interactive way.

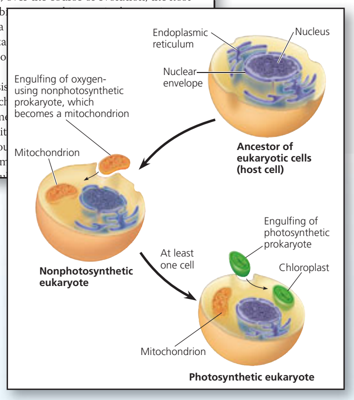
Focus on Evolution

Every chapter has a section explicitly relating the chapter content to **evolution**, the fundamental theme of biology. Each section is highlighted by an Evolution banner.

The Evolutionary Origins of Mitochondria and Chloroplasts

EVOLUTION Mitochondria and chloroplasts display similarities with bacteria that led to the **endosymbiont theory**, illustrated in **Figure 4.16**. This theory states that an early ancestor of eukaryotic cells engulfed an oxygen-using nonphotosynthetic prokaryotic cell. Eventually, the engulfed cell formed a relationship with the host cell in which it was enclosed, becoming an *endosymbiont* (a cell living within another cell). Indeed, over the course of evolution, the host cell and its endosymb... eukaryotic cell with a ... cells may have then ta... becoming the ancesto... chloroplasts.

This theory is consis... of mitochondria and cl... bounded by a single m... membrane system, mit... two membranes surrou... an internal system of m... that the ancestral engu...



Review and Test Understanding

Chapter Reviews help students master the chapter content by focusing on the main points and offering opportunities to practice for exams.

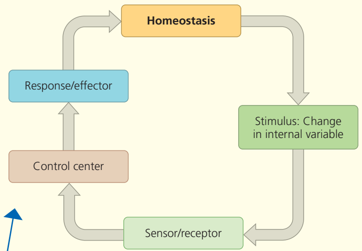
32 Chapter Review

SUMMARY OF KEY CONCEPTS

CONCEPT 32.1

Feedback control maintains the internal environment in many animals (pp. 642–647)

- Animal bodies are based on a hierarchy of cells, **tissues**, **organs**, and **organ systems**. **Epithelial tissue** forms active interfaces on external and internal surfaces; **connective tissue** binds and supports other tissues; **muscle tissue** contracts, moving body parts; and **nervous tissue** transmits nerve impulses throughout the body.
- Animals *regulate* certain internal variables while allowing other internal variables to *conform* to external changes. **Homeostasis** is the maintenance of a steady state despite internal and external changes.



- An animal maintains its internal temperature within a tolerable range by **thermoregulation**. **Endotherms** are warmed mostly by heat generated by metabolism. **Ectotherms** get most of their heat from external sources. The **hypothalamus** acts as the thermostat in mammalian regulation of body temperature.

? *Given that humans thermoregulate, explain why your skin is cooler than your body core.*

CONCEPT 32.2

Endocrine signals trigger homeostatic mechanisms in target tissues (pp. 648–653)

- In communicating between different locations in the body, the **endocrine system** broadcasts signaling molecules called **hormones** everywhere via the bloodstream. Only certain cells are responsive to each hormone. The **nervous system** uses dedicated cellular circuits involving electrical and chemical signals to send information to specific locations. Hormone pathways may be regulated by **negative feedback**, which damps the stimulus, or **positive feedback**, which amplifies the stimulus and drives the response to completion.

? *Why would a water-soluble hormone likely have no effect if injected directly into the cytosol of a target cell?*

CONCEPT 32.3

A shared system mediates osmoregulation and excretion in many animals (pp. 653–658)

- When blood **osmolarity** rises, the posterior pituitary releases **antidiuretic hormone (ADH)**, which increases permeability to water in collecting ducts by increasing the number of water channels. When blood pressure or blood volume in the afferent arteriole drops, the **juxtaglomerular apparatus (JGA)** releases renin. **Angiotensin II**, formed in response to renin, constricts arterioles and triggers release of the hormone **aldosterone**, raising blood pressure. This **renin-angiotensin-aldosterone system (RAAS)** has functions that overlap with those of ADH.

? *How do cortical nephrons and juxtamedullary nephrons differ in reabsorbing nutrients and concentrating urine?*

TEST YOUR UNDERSTANDING

Level 1: Knowledge/Comprehension

1. The body tissue that consists largely of material located outside of cells is
   a. epithelial tissue.
   b. connective tissue.
   c. skeletal muscle.
   d. smooth muscle.
   e. nervous tissue.
2. Which of the following would increase the rate of heat exchange between an animal and its environment?
   a. feathers or fur
   b. vasoconstriction
   c. wind blowing across the body surface
   d. countercurrent heat exchanger
   e. blubber or fat layer
3. Which process in the nephron is *least* selective?
   a. filtration
   b. reabsorption
   c. active transport
   d. secretion
   e. salt pumping by the loop of Henle

Level 2: Application/Analysis

4. Homeostasis typically relies on negative feedback because positive feedback
   a. requires a response but not a stimulus.
   b. drives processes to completion rather than to a balance point.
   c. acts within, but not beyond, a normal range.
   d. can decrease but not increase a variable.
   e. involves one location rather than several across the body.
5. Which of the following is an accurate statement about thermoregulation?
   a. Endotherms are regulators and ectotherms are conformers.
   b. Endotherms maintain a constant body temperature and ectotherms do not.
   c. Endotherms are warm-blooded and ectotherms are cold-blooded.
   d. Endotherms and ectotherms differ in their primary source of heat for thermoregulation.
   e. Endothermy has a lower energy cost than ectothermy.
6. Natural selection should favor the highest proportion of juxtamedullary nephrons in which of the following species?
   a. a river otter
   b. a mouse species living in a tropical rain forest
   c. a mouse species living in a temperate broadleaf forest
   d. a mouse species living in a desert
   e. a beaver
7. African lungfish, which are often found in small stagnant pools of fresh water, produce urea as a nitrogenous waste. What is the advantage of this adaptation?
   a. Urea takes less energy to synthesize than ammonia.
   b. Small stagnant pools do not provide enough water to dilute the toxic ammonia.
   c. The highly toxic urea makes the pool uninhabitable to potential competitors.
   d. Urea forms an insoluble precipitate.
   e. Urea makes lungfish tissue hypoosmotic to the pool.

Level 3: Synthesis/Evaluation

8. DRAW IT Draw a model of the control circuit(s) required for driving an automobile at a fairly constant speed over a hilly road. Indicate each feature that represents a sensor, stimulus, or response.
9. SCIENTIFIC INQUIRY
   You are exploring kidney function in kangaroo rats. You measure urine volume and osmolarity, as well as the amount of chloride ions (Cl^-) and urea in the urine. If the water source provided to the animals were switched from tap water to a 2% NaCl solution, what change in urine osmolarity would you expect? How would you determine if this change was more likely due to a change in the excretion of Cl^- or urea?
10. FOCUS ON EVOLUTION
    Merriam's kangaroo rats (*Dipodomys merriami*) live in North American habitats ranging from moist, cool woodlands to hot deserts. Assuming that natural selection has resulted in differences in water conservation between *D. merriami* populations, propose a hypothesis concerning the relative rates of evaporative water loss by populations that live in moist versus dry environments. Using a humidity sensor to detect evaporative water loss by kangaroo rats, how could you test your hypothesis?
11. FOCUS ON ORGANIZATION
    In a short essay (100–150 words), compare how membrane structures in the loop of Henle and collecting duct of the mammalian kidney enable water to be recovered from filtrate in the process of osmoregulation.

For selected answers, see Appendix A.

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Students Go to **www.masteringbiology.com** for assignments, the eText, and the Study Area with practice tests, animations, and

Summary of Key Concepts questions check students' understanding of a key idea from each concept.

Scientific Inquiry questions ask students to practice scientific thinking by developing hypotheses, designing experiments, and analyzing real research data.

Summary figures present key information in a visual way.

Test Your Understanding questions are organized into three levels based on Bloom's Taxonomy.

Focus on a Theme questions give students practice writing a short essay that connects the chapter's content to the five bookwide themes introduced in Chapter 1: **Evolution, Organization, Information, Energy and Matter,** and **Interactions.**

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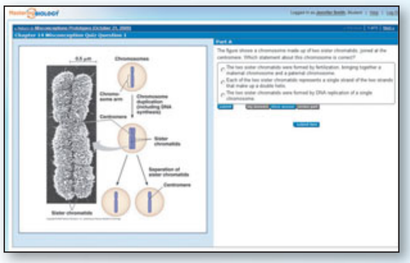
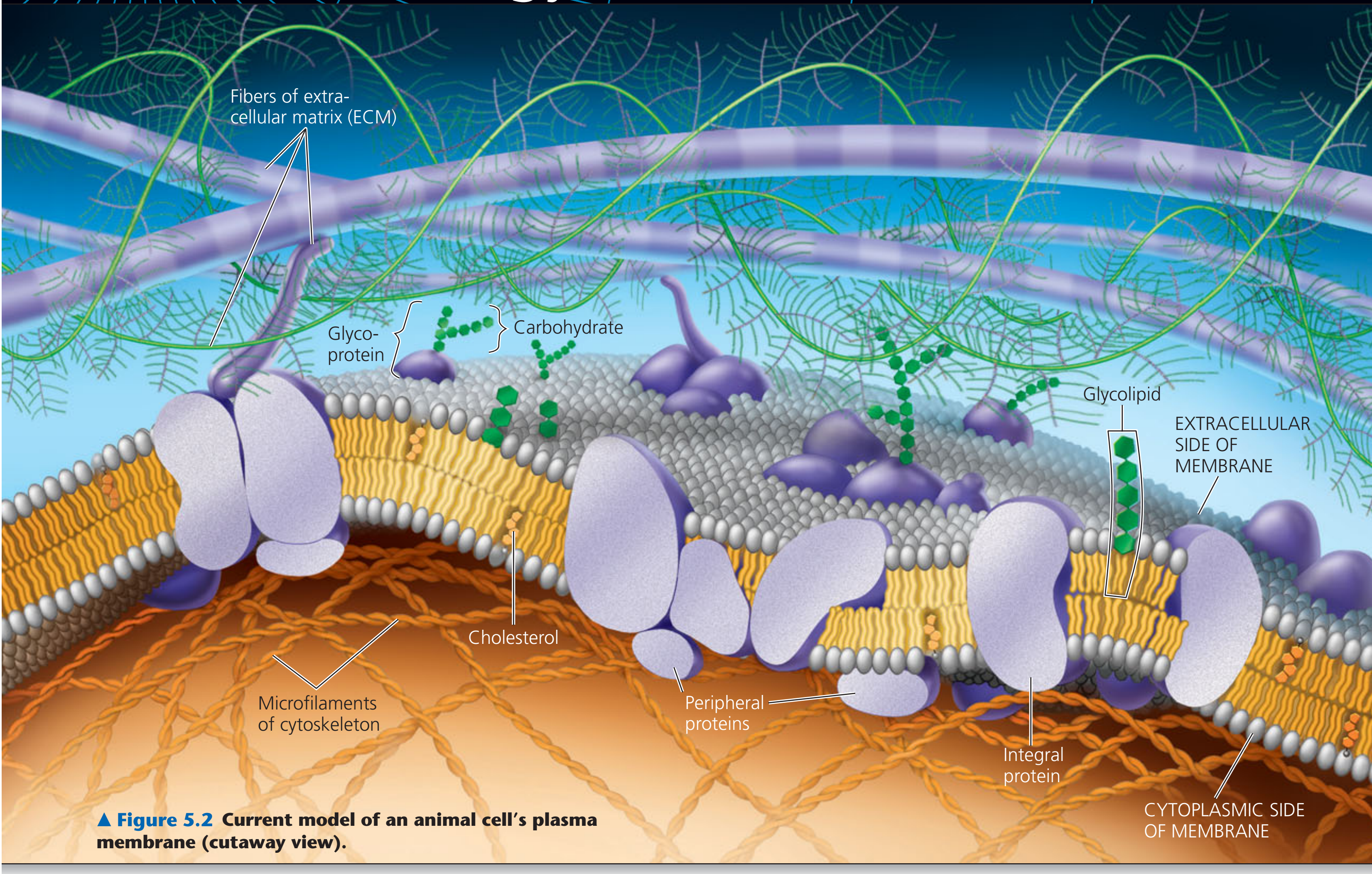


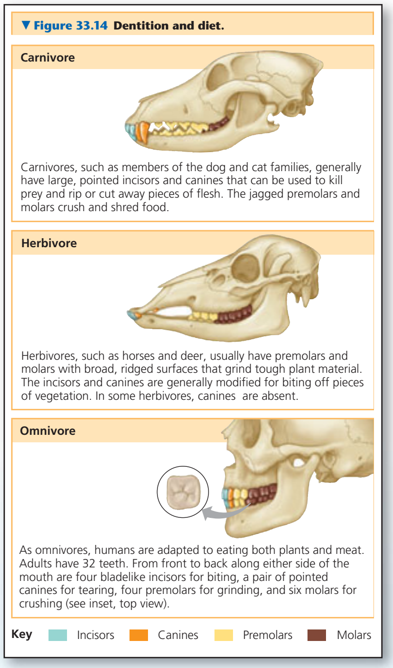
Student Misconception Questions provide assignable quizzes for each chapter to assess and remediate common student misconceptions.

Visualize Biology



▲ **Figure 5.2 Current model of an animal cell's plasma membrane (cutaway view).**

▲ Selected figures are rendered in a **3-D style** to help students visualize biological structures.



◀ **Visual Organizers** highlight the main parts of a figure, helping students see the key categories at a glance.

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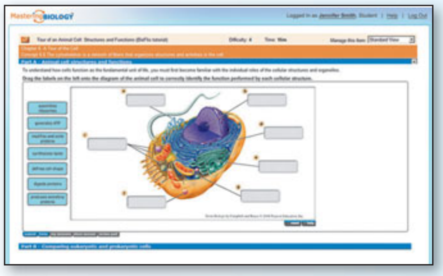
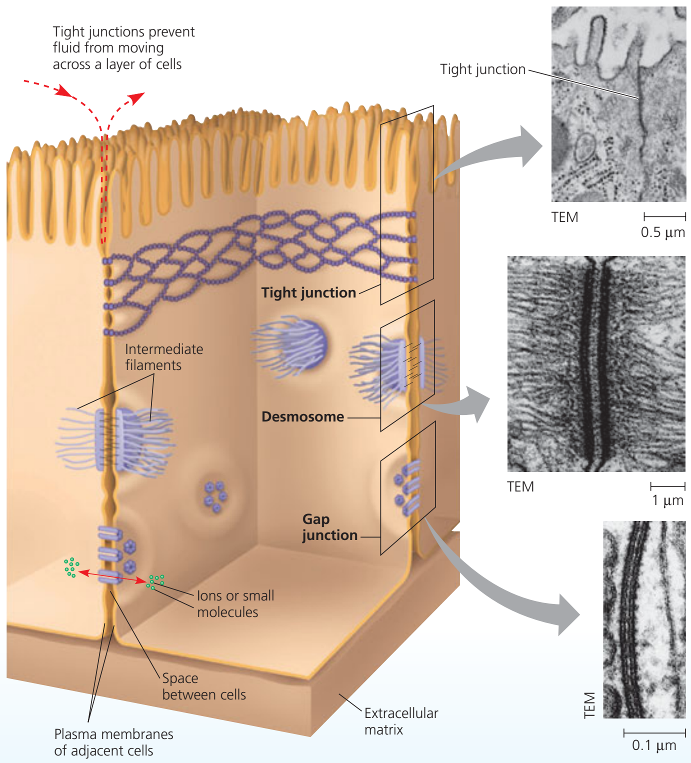


Many **Tutorials** and **Activities** integrate art from the textbook, providing a unified learning experience.

▼ Figure 4.27 Exploring Cell Junctions in Animal Tissues



Tight Junctions

At **tight junctions**, the plasma membranes of neighboring cells are very tightly pressed against each other, bound together by specific proteins (purple). Forming continuous seals around the cells, tight junctions prevent leakage of extracellular fluid across a layer of epithelial cells. For example, tight junctions between skin cells make us watertight by preventing leakage between cells in our sweat glands.

Desmosomes

Desmosomes (also called anchoring junctions) function like rivets, fastening cells together into strong sheets. Intermediate filaments made of sturdy keratin proteins anchor desmosomes in the cytoplasm. Desmosomes attach muscle cells to each other in a muscle. Some "muscle tears" involve the rupture of desmosomes.

Gap Junctions

Gap junctions (also called communicating junctions) provide cytoplasmic channels from one cell to an adjacent cell and in this way are similar in their function to the plasmodesmata in plants. Gap junctions consist of membrane proteins that surround a pore through which ions, sugars, amino acids, and other small molecules may pass. Gap junctions are necessary for communication between cells in many types of tissues, such as heart muscle, and in animal embryos.

◀ By integrating text, art, and photos, **Exploring Figures** help students access information efficiently.

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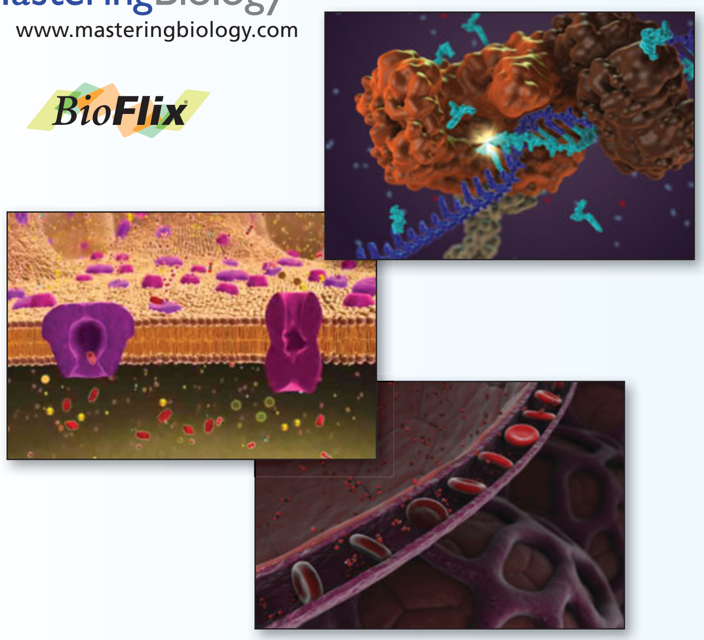

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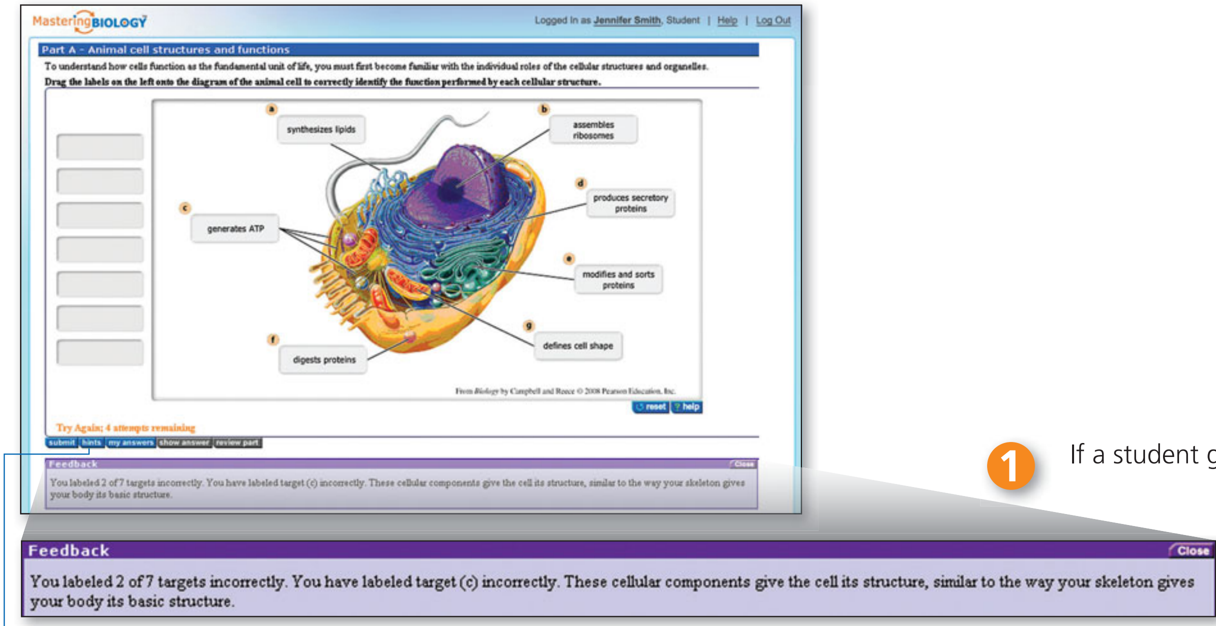
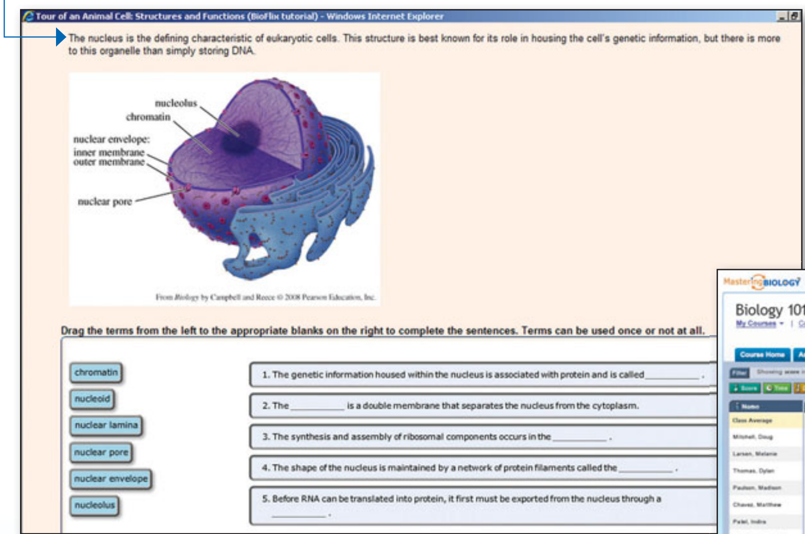
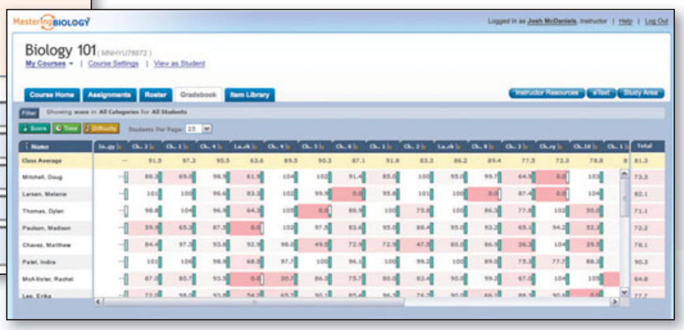


1 If a student gets stuck…

2 …specific wrong-answer **feedback** appears in the purple feedback box.

3 **Hints** coach the student to the correct response.





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Students can use the Study Area on their own or in a study group.

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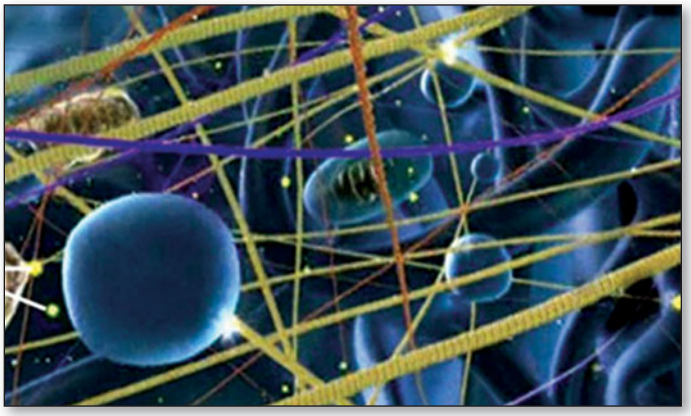

▲ **BioFlix 3-D Animations** explore the most difficult biology topics, reinforced with tutorials, quizzes, and more.

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- Cumulative Test
- MP3 Tutor Sessions
- Videos
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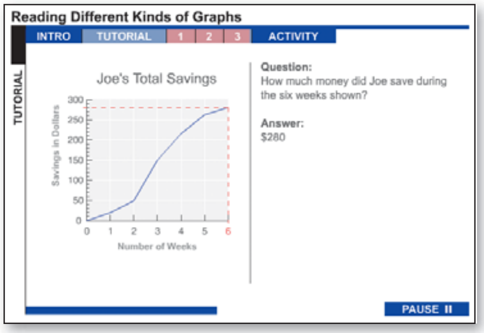

▲ **Get Ready for Biology** helps students get up to speed for their course by covering study skills, basic math review, terminology, biology basics, chemistry, and cell biology.

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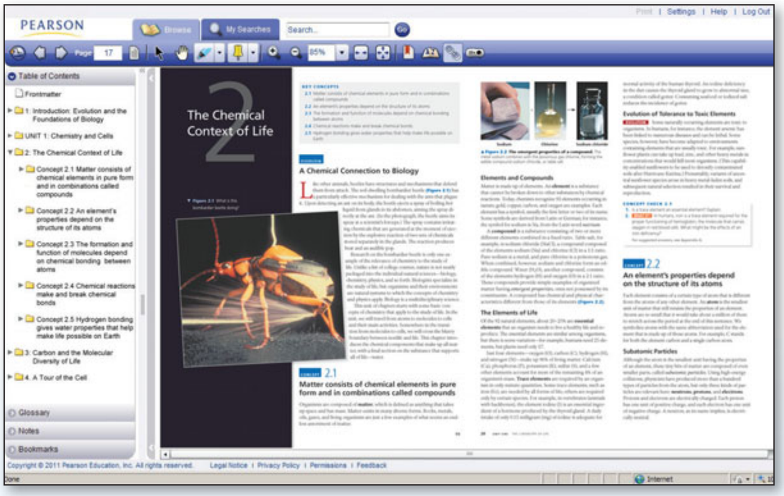

◀ The Pearson **eText** gives students access to the text whenever and wherever they can access the Internet. The eText can be viewed on PCs, Macs, and tablets, including iPad and Android. The eText includes powerful interactive and customization functions:

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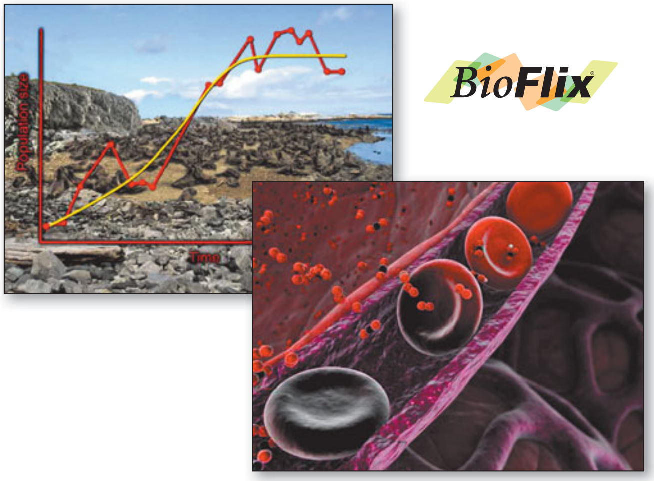
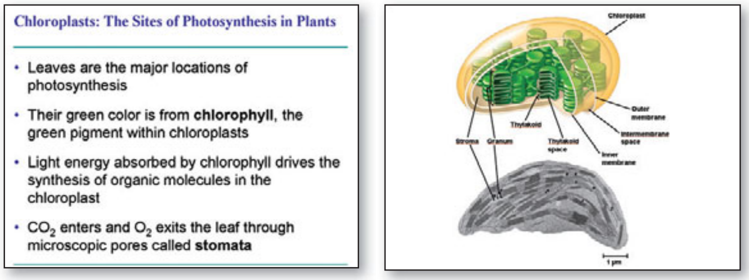
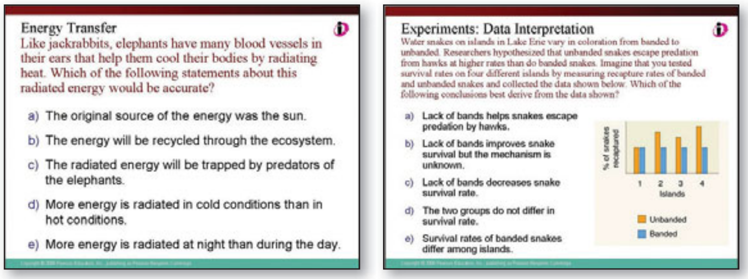


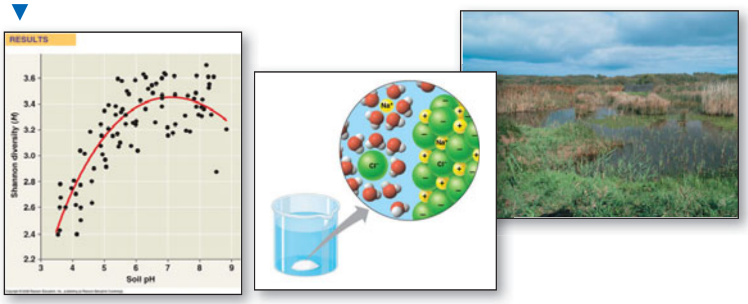
Customizable PowerPoints provide a jumpstart for each lecture.



Clicker Questions can be used to stimulate effective classroom discussions (for use with or without clickers).



All of the art and photos from the book are provided with customizable labels.



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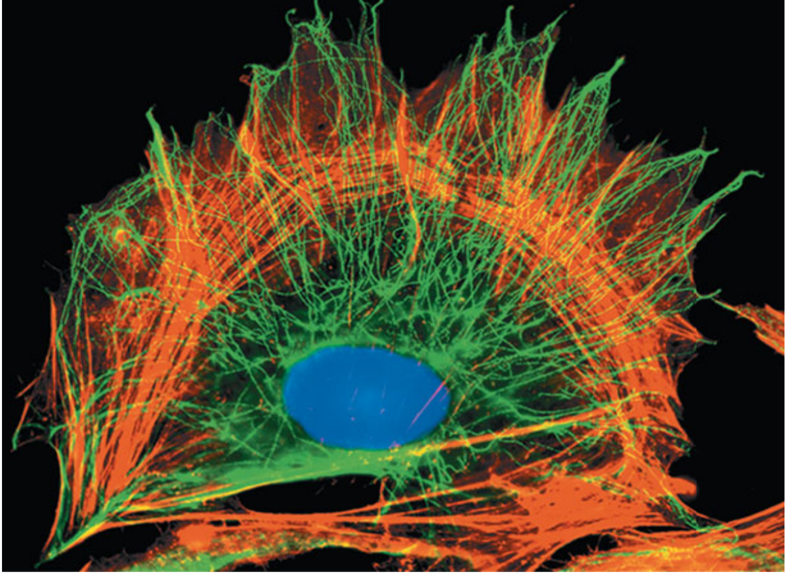

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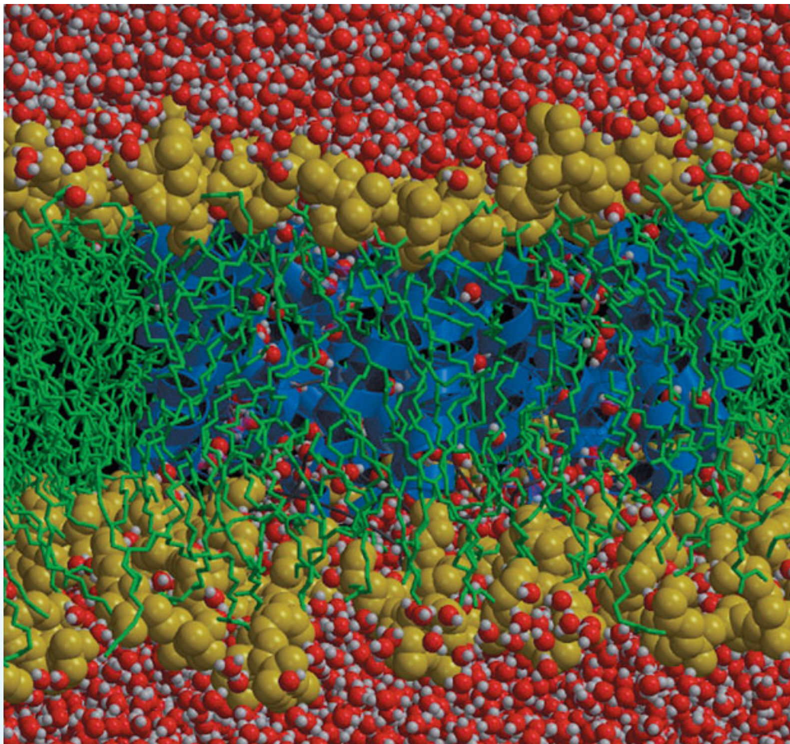

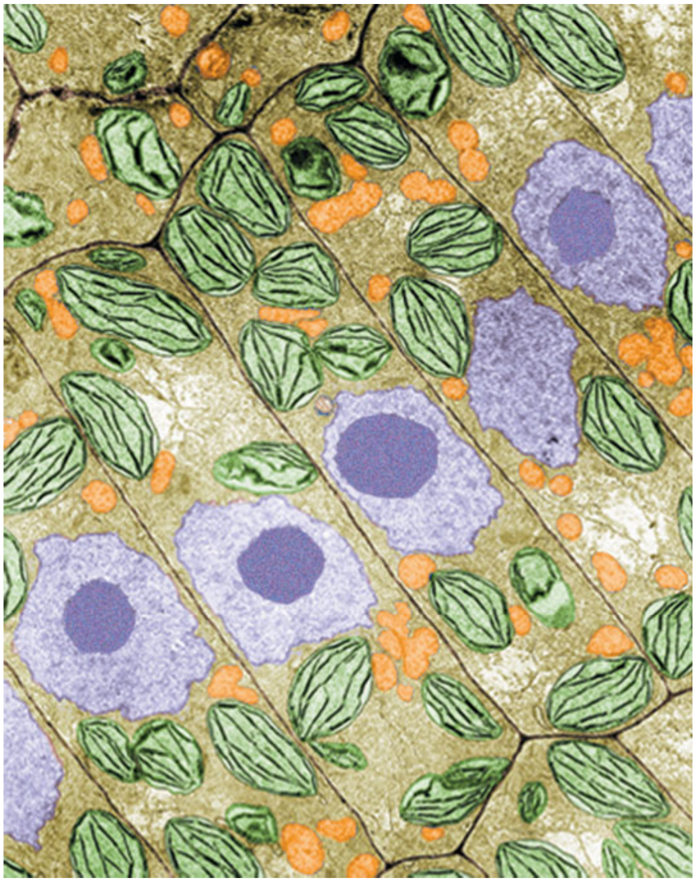

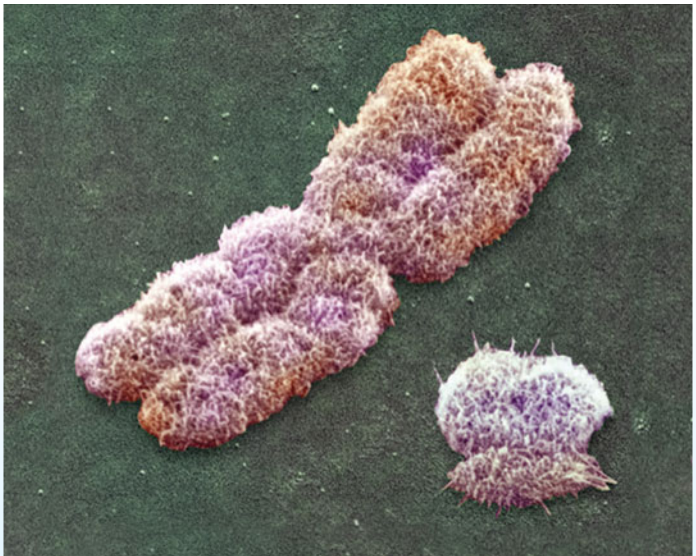

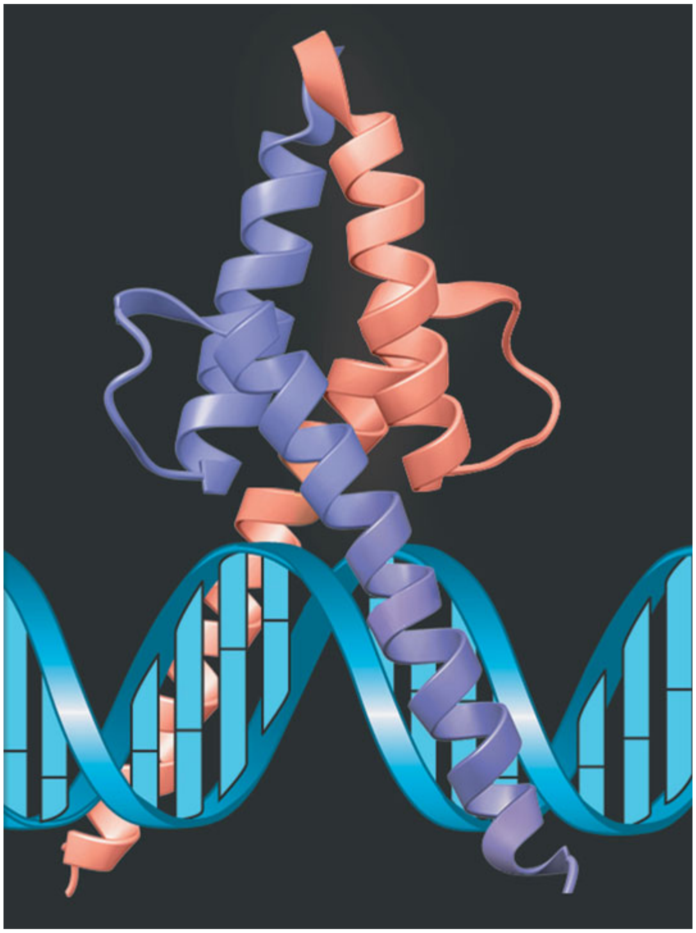

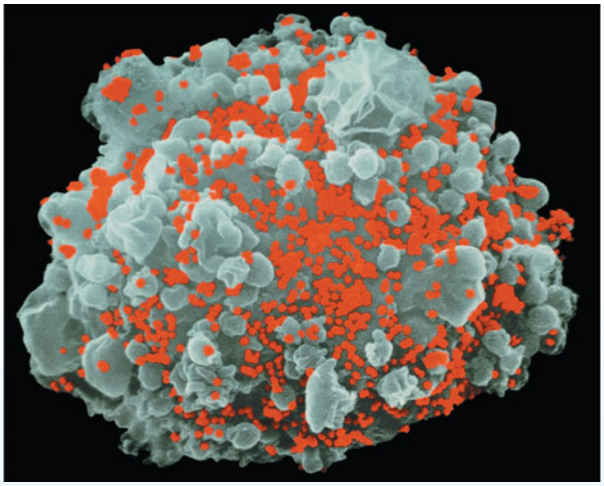

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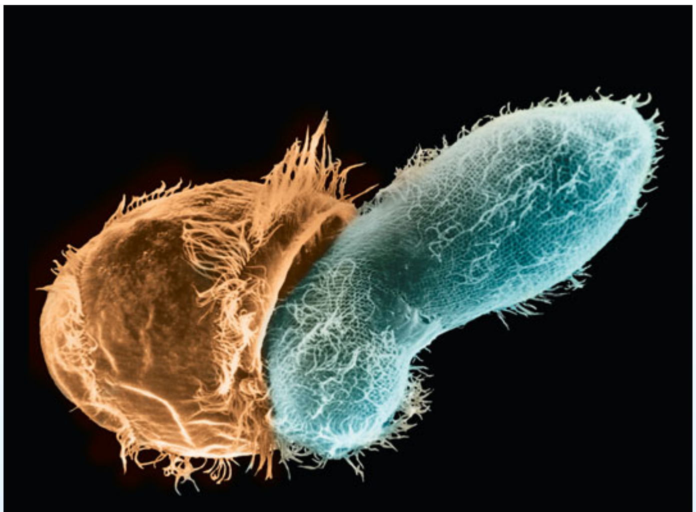

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1 Introduction: Evolution and the Foundations of Biology

▼ **Figure 1.1** What can this beach mouse teach us about biology?

KEY CONCEPTS

1.1 Studying the diverse forms of life reveals common themes

1.2 The Core Theme: Evolution accounts for the unity and diversity of life

1.3 Biological inquiry entails forming and testing hypotheses based on observations of nature

OVERVIEW

Inquiring About Life

The brilliant white sand dunes and sparse clumps of beach grass along the Florida seashore afford little cover for the beach mice that live there. However, a beach mouse's light, dappled fur acts as camouflage, allowing the mouse to blend into its surroundings **(Figure 1.1)**. Although mice of the same species (oldfield mice, *Peromyscus polionotus*) also inhabit nearby inland areas, the inland mice are much darker in color, matching the darker soil and vegetation where they live **(Figure 1.2)**. This close match of each mouse to its environment is vital for survival, since hawks, herons, and other sharp-eyed predators periodically scan the landscape for food. How has the color of each mouse come to be so well matched, or *adapted*, to the local background?

An organism's adaptations to its environment, such as camouflage that helps protect it from predators, are the result of **evolution**, the process of change that has transformed life from its beginnings to the astounding array of organisms today. Evolution is the fundamental principle of biology and the core theme of this book.

Although biologists know a great deal about life on Earth, many mysteries remain. The question of how the mice's coats have come to match the colors of their habitats is just one example. Posing questions about the living world and seeking answers through scientific inquiry are the central activities of **biology**, the scientific study of life. Biologists' questions can be ambitious. They may ask how a single tiny cell becomes a tree or a dog, how the human mind works, or how the different forms of life in a forest interact. When questions occur to you as you observe the living world, you are already thinking like a biologist.

How do biologists make sense of life's diversity and complexity? This opening chapter sets up a framework for answering this question. The first part of the chapter provides a panoramic view of the biological "landscape," organized around a set of unifying themes. We'll then focus on biology's core theme, evolution. Finally, we'll examine the process of scientific inquiry—how scientists ask and attempt to answer questions about the natural world.

▶ **Figure 1.2 An "inland" oldfield mouse (*Peromyscus polionotus*).** This mouse has a much darker back, side, and face than mice of the same species that inhabit sand dunes.

CONCEPT 1.1

Studying the diverse forms of life reveals common themes

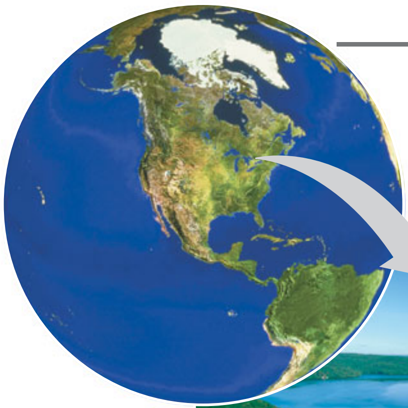
Biology is a subject of enormous scope, and exciting new biological discoveries are being made every day. How can you organize and make sense of all the information you'll encounter as you study biology? Focusing on a few big ideas—ways of thinking about life that will still hold true decades from now—will help. Here, we'll describe five unifying themes to serve as touchstones as you proceed through this book.

Theme: New Properties Emerge at Successive Levels of Biological Organization

ORGANIZATION The study of life extends from the microscopic scale of the molecules and cells that make up organisms to the global scale of the entire living planet. As biologists, we can divide this enormous range into different levels of biological organization.

Imagine zooming in from space to take a closer and closer look at life on Earth. It is spring in Ontario, Canada, and our destination is a local forest, where we will eventually narrow our focus down to the molecules that make up a maple leaf. **Figure 1.3** narrates this journey into life, as the numbers guide

▼ Figure 1.3 **Exploring Levels of Biological Organization**



◀ 1 The Biosphere

Even from space, we can see signs of Earth's life—in the green mosaic of the forests, for example. We can also see the scale of the entire biosphere, which consists of all life on Earth and all the places where life exists: most regions of land, most bodies of water, the atmosphere to an altitude of several kilometers, and even sediments far below the ocean floor.

◀ 2 Ecosystems

Our first scale change brings us to a North American forest with many deciduous trees (trees that lose their leaves and grow new ones each year). A deciduous forest is an example of an ecosystem, as are grasslands, deserts, and coral reefs. An ecosystem consists of all the living things in a particular area, along with all the nonliving components of the environment with which life interacts, such as soil, water, atmospheric gases, and light.

▶ 3 Communities

The array of organisms inhabiting a particular ecosystem is called a biological community. The community in our forest ecosystem includes many kinds of trees and other plants, various animals, mushrooms and other fungi, and enormous numbers of diverse microorganisms, which are living forms, such as bacteria, that are too small to see without a microscope. Each of these forms of life is called a *species*.

▶ 4 Populations

A population consists of all the individuals of a species living within the bounds of a specified area. For example, our forest includes a population of sugar maple trees and a population of white-tailed deer. A community is therefore the set of populations that inhabit a particular area.

▲ 5 Organisms

Individual living things are called organisms. Each of the maple trees and other plants in the forest is an organism, and so is each deer, frog, beetle, and other forest animals. The soil teems with microorganisms such as bacteria.

you through photographs illustrating the hierarchy of biological organization.

Zooming in at ever-finer resolution illustrates the principle of *reductionism*—the approach of reducing complex systems to simpler components that are more manageable to study. Reductionism is a powerful strategy in biology. For example, by studying the molecular structure of DNA that had been extracted from cells, James Watson and Francis Crick inferred the chemical basis of biological inheritance. However, although it has propelled many major discoveries, reductionism provides a necessarily incomplete view of life on Earth, as we'll discuss next.

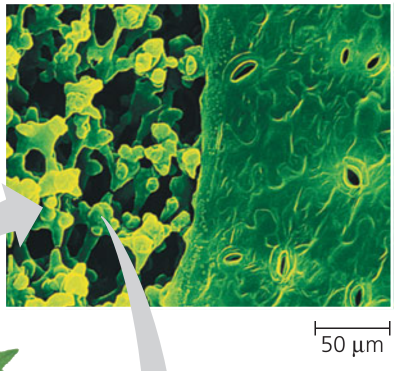
Emergent Properties

Let's reexamine Figure 1.3, beginning this time at the molecular level and then zooming out. Viewed this way, we see that at each level, novel properties emerge that are absent from the preceding one. These **emergent properties** are due to the arrangement and interactions of parts as complexity increases. For example, although photosynthesis occurs in an intact chloroplast, it will not take place in a disorganized test-tube mixture of chlorophyll and other chloroplast molecules. The coordinated processes of photosynthesis require a specific organization of these molecules in the chloroplast. Isolated components of living systems, acting as the objects of study in

▼ 6 Organs and Organ Systems

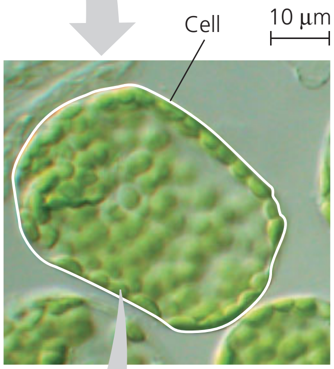
The structural hierarchy of life continues to unfold as we explore the architecture of more complex organisms. A maple leaf is an example of an organ, a body part that carries out a particular function in the body. Stems and roots are the other major organs of plants. The organs of complex animals and plants are organized into organ systems, each a team of organs that cooperate in a larger function. Organs consist of multiple tissues.

◀ 7 Tissues



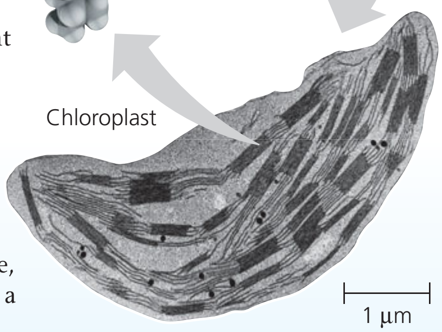
To see the tissues of a leaf requires a microscope. Each tissue is a group of cells that work together, performing a specialized function. The leaf shown here has been cut on an angle. The honeycombed tissue in the interior of the leaf (left side of photo) is the main location of photosynthesis, the process that converts light energy to the chemical energy of sugar. The jigsaw puzzle–like "skin" on the surface of the leaf is a tissue called epidermis (right side of photo). The pores through the epidermis allow entry of the gas CO_2, a raw material for sugar production.

▲ 8 Cells



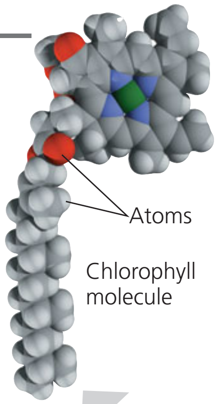
The cell is life's fundamental unit of structure and function. Some organisms are single cells, while others are multicellular. A single cell performs all the functions of life, while a multicellular organism has a division of labor among specialized cells. Here we see a magnified view of cells in a leaf tissue. One cell is about 40 micrometers (µm) across—about 500 of them would reach across a small coin. As tiny as these cells are, you can see that each contains numerous green structures called chloroplasts, which are responsible for photosynthesis.

▶ 9 Organelles



Chloroplasts are examples of organelles, the various functional components present in cells. This image, taken by a powerful microscope, shows a single chloroplast.

▶ 10 Molecules



Our last scale change drops us into a chloroplast for a view of life at the molecular level. A molecule is a chemical structure consisting of two or more units called atoms, represented as balls in this computer graphic of a chlorophyll molecule. Chlorophyll is the pigment molecule that makes a maple leaf green, and it absorbs sunlight during photosynthesis. Within each chloroplast, millions of chlorophyll molecules are organized into systems that convert light energy to the chemical energy of food.

a reductionist approach to biology, typically lack some of the properties that emerge at higher levels of organization.

Emergent properties are not unique to life. A box of bicycle parts won't transport you anywhere, but if they are arranged in a certain way, you can pedal to your chosen destination. Compared to such nonliving examples, however, the unrivaled complexity of biological systems makes the emergent properties of life especially challenging to study.

To fully explore emergent properties, biologists today complement reductionism with **systems biology**, the exploration of a biological system by analyzing the interactions among its parts. A single leaf cell can be considered a system, as can a frog, an ant colony, or a desert ecosystem. By examining and modeling the dynamic behavior of an integrated network of components, systems biology enables us to pose new kinds of questions. For example, how does a drug that lowers blood pressure affect the functioning of organs throughout the body? At a larger scale, how does a gradual increase in atmospheric carbon dioxide alter ecosystems and the entire biosphere? Systems biology can be used to study life at all levels.

Structure and Function

At each level of the biological hierarchy, we find a correlation of structure and function. Consider the leaf in Figure 1.3: Its thin, flat shape maximizes the capture of sunlight by chloroplasts. More generally, analyzing a biological structure gives us clues about what it does and how it works. Conversely, knowing the function of something provides insight into its structure and organization. Many examples from the animal kingdom show a correlation between structure and function, including the hummingbird **(Figure 1.4)**. The hummingbird's anatomy allows the wings to rotate at the shoulder, so hummingbirds have the ability, unique among birds, to fly backward or hover in place. Hovering, the birds can extend their long slender beaks into flowers and feed on nectar. The elegant match of form and function in the structures of life is explained by natural selection, as we'll explore shortly.

▲ **Figure 1.4 Form fits function in a hummingbird's body.** The unusual bone structure of a hummingbird's wing allows the bird to rotate its wings in all directions, enabling it to fly backward and to hover while it feeds.

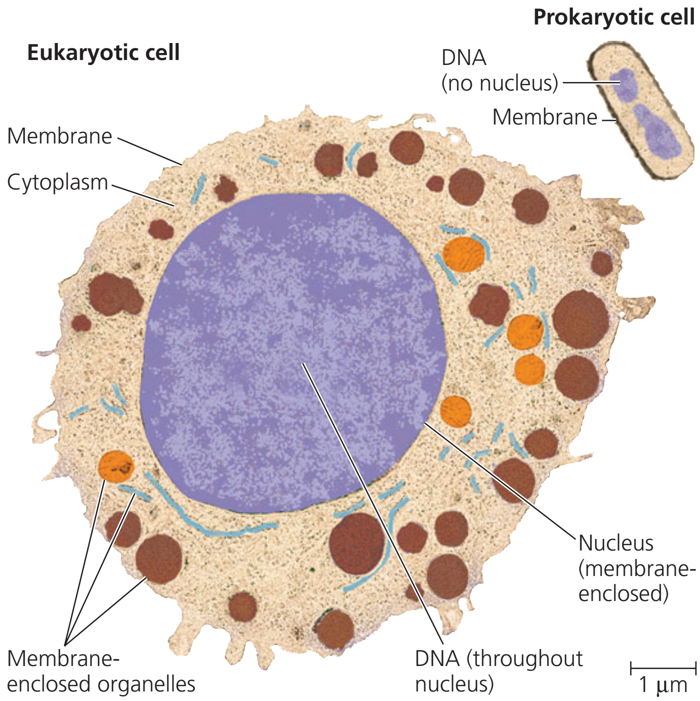
? *What other examples of form fitting function do you observe in this photograph?*

The Cell: An Organism's Basic Unit of Structure and Function

In life's structural hierarchy, the cell is the smallest unit of organization that can perform all required activities. In fact, the activities of organisms are all based on the activities of cells. For instance, the movement of your eyes as you read this sentence results from the activities of muscle and nerve cells. Even a process that occurs on a global scale, such as the recycling of carbon atoms, is the cumulative product of cellular functions, including the photosynthetic activity of chloroplasts in leaf cells.

All cells share certain characteristics. For instance, every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings. Nevertheless, we recognize two main forms of cells: prokaryotic and eukaryotic. The cells of two groups of single-celled microorganisms—bacteria (singular, *bacterium*) and archaea (singular, *archaean*)—are prokaryotic. All other forms of life, including plants and animals, are composed of eukaryotic cells.

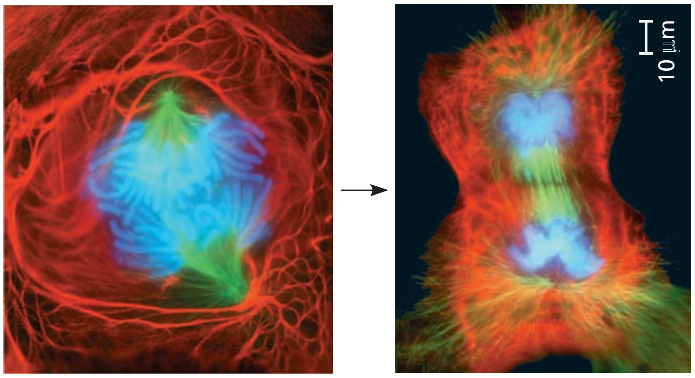
A **eukaryotic cell** contains membrane-enclosed organelles **(Figure 1.5)**. Some organelles, such as the DNA-containing nucleus, are found in the cells of all eukaryotes; other organelles are specific to particular cell types. For example, the chloroplast in Figure 1.3 is an organelle found only in eukaryotic cells that carry out photosynthesis. In contrast to eukaryotic cells, a **prokaryotic cell** lacks a nucleus or other membrane-enclosed organelles. Furthermore, prokaryotic cells are generally smaller than eukaryotic cells, as shown in Figure 1.5.



▲ **Figure 1.5 Contrasting eukaryotic and prokaryotic cells in size and complexity.**

Theme: Life's Processes Involve the Expression and Transmission of Genetic Information

INFORMATION Within cells, structures called chromosomes contain genetic material in the form of **DNA (deoxyribonucleic acid)**. In cells that are preparing to divide, the chromosomes may be made visible using a dye that appears blue when bound to the DNA **(Figure 1.6)**.



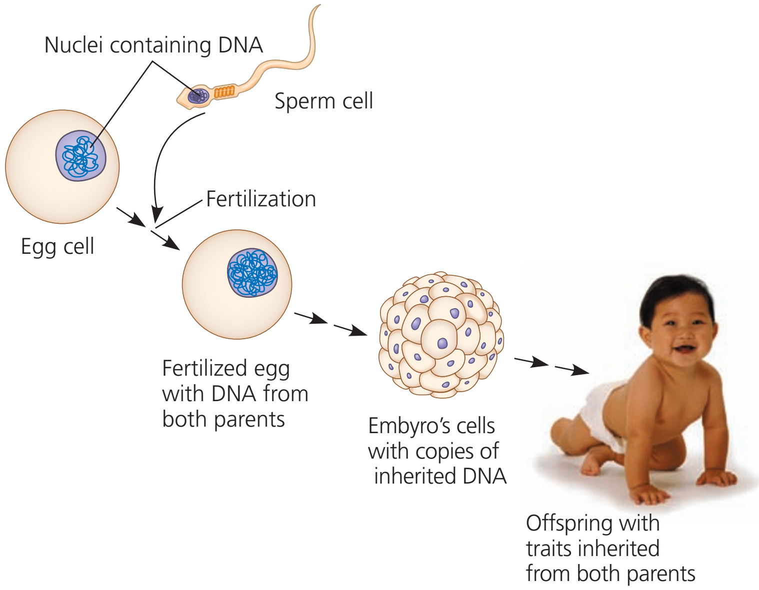
▲ **Figure 1.6 A lung cell from a newt divides into two smaller cells that will grow and divide again.**

DNA Structure and Function

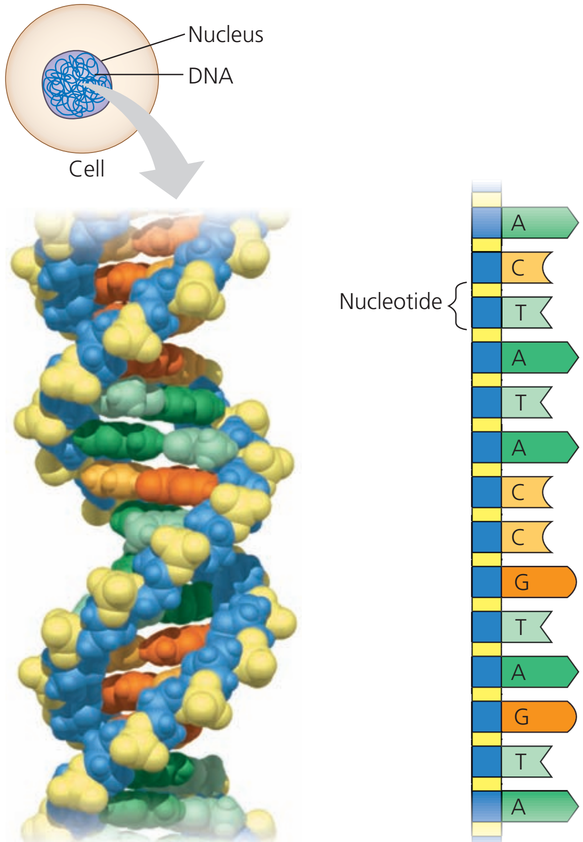
Each time a cell divides, the DNA is first *replicated*, or copied, and each of the two cellular offspring inherits a complete set of chromosomes, identical to that of the parent cell. Each chromosome contains one very long DNA molecule with hundreds or thousands of **genes**, each a stretch of DNA arranged along the chromosome. Transmitted from parents to offspring, genes are the units of inheritance. They encode the information necessary to build all of the molecules synthesized within a cell, which in turn establish that cell's identity and function. Each of us began as a single cell stocked with DNA inherited from our parents. The replication of that DNA during each round of cell division transmitted copies of the DNA to what eventually became the trillions of cells of the human body. As the cells grew and divided, the genetic information encoded by the DNA directed our development **(Figure 1.7)**.

The molecular structure of DNA accounts for its ability to store information. A DNA molecule is made up of two long chains, called strands, arranged in a double helix. Each chain is made up of four kinds of chemical building blocks called nucleotides, abbreviated A, T, C, and G **(Figure 1.8)**. The way DNA encodes information is analogous to how we arrange the letters of the alphabet into words and phrases with specific meanings. The word *rat*, for example, evokes a rodent; the words *tar* and *art*, which contain the same letters, mean very different things. We can think of nucleotides as a four-letter alphabet. Specific sequences of these four nucleotides encode the information in genes.

DNA provides the blueprints for making proteins, which are the major players in building and maintaining the cell and



▲ **Figure 1.7 Inherited DNA directs development of an organism.**



(a) DNA double helix. This model shows each atom in a segment of DNA. Made up of two long chains of building blocks called nucleotides, a DNA molecule takes the three-dimensional form of a double helix.

(b) Single strand of DNA. These geometric shapes and letters are simple symbols for the nucleotides in a small section of one chain of a DNA molecule. Genetic information is encoded in specific sequences of the four types of nucleotides. (Their names are abbreviated A, T, C, and G.)

▲ **Figure 1.8 DNA: The genetic material.**