



BIOLOGY

THE DYNAMIC SCIENCE THIRD EDITION

Russell Hertz McMillan



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Click on any one of the following three crosses to proceed. There is no right or wrong choice, but you will be responsible for analyzing the inheritance pattern of a particular trait based on observations of the parents you choose and the pups that they produce.



Saluki

X





Basset hound

Option 1:
• German shepherd X basset hound

Option 2:
• **Saluki X basset hound**

Option 3:
• dachshund X Boston terrier

The following photograph shows two offspring from your chosen cross. These offspring are representative of all offspring produced in this cross.



Based on these results, which of the following traits is recessive?

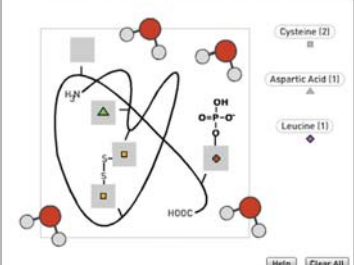
Short, bent legs of the basset

Long, straight legs of the saluki

The black line in the following illustration represents the peptide backbone of a 100 amino acid-long protein that has properly folded into its three-dimensional conformation. The five grey boxes represent the R groups of five of the amino acids in this protein: two cysteines, one aspartic acid, one leucine, and one threonine. These five amino acids are located in various positions along the chain. The red cross within the grey box shows the position of the R group of threonine along this protein.

This particular threonine is special because it has been modified with _____ group.

Predict where the remaining four amino acids belong in the protein based on their functional groups and affinity for water, which surrounds the outside of the protein. Drag each of their corresponding points into the correct grey box.



Cysteine (2) II

Aspartic Acid (1) ▲

Leucine (1) ◆

[Help](#) [Clear All](#)

Get actively involved in the process of learning and doing biology

Interactive animations and videos within problems reinforce key concepts, tying your homework to the textbook and helping you visualize dynamic biological processes.

A human cell packs more than 2 m of DNA into a nucleus that is 10 μm wide. Watch the adjacent silent video to see how our DNA is packed in a cell that is preparing for mitosis.

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Note: Video is silent.

The following five images are screen captures taken from this video.

In the following table, correctly identify each image. Then, order the images based on the relative size of the structures pictured.

Image	Description
A	?
B	?
C	?
D	?
E	?

Smallest Structure
Image <input type="text"/>
Image <input type="text"/>
Image <input type="text"/>
Image <input type="text"/>
Image <input type="text"/>

Largest Structure
Image <input type="text"/>
Image <input type="text"/>
Image <input type="text"/>
Image <input type="text"/>
Image <input type="text"/>

The following graph depicts changes in the duration of nighttime over the course of the year at four different latitudes in the United States. You can highlight a particular curve by rolling your cursor over the curve or its caption.

Data from the National Oceanic and Atmospheric Administration, <http://www.noaa.com>

Solanum tuberosum andigena, or the Andean potato, is a long-day (short-night) plant with a critical night length of around 12 hours. If you grow this plant outdoors in Baltimore, you would expect it to _____ . If you grow this plant outdoors in Miami, you would expect it to _____ .

Imagine that you choose to grow Andean potato indoors. Now you can control the timing and duration of illumination that the plants receive each day. In three separate rooms of your greenhouse, you set up three separate daily light regimens: (1) 15 hours of light followed by 9 hours of dark, (2) 9 hours of light followed by 15 hours of dark, and (3) the same regimen but with a brief flash of light 7 hours after the onset of dark.

In the boxes below, predict whether the plants will flower under each of these regimens.

-
-
-

Diverse and engaging problems include data analysis, experimental and observational approaches to research, real-world applications, and global problems to increase your critical thinking, analytic, and problem-solving skills.

BIOLOGY

THE DYNAMIC SCIENCE THIRD EDITION

Russell Hertz McMillan

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Biology: The Dynamic Science, Third Edition
**Peter J. Russell, Paul E. Hertz, Beverly
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Developmental Editors: Shelley Parlante,
Jake Warde, Suzannah Alexander

Assistant Editor: Alexis Glubka

Editorial Assistants: Lauren Crosby, Sean Cronin

Media Editor: Lauren Oliveira

Brand Manager: Nicole Hamm

Market Development Manager: Tom Ziolkowski

Content Project Manager: Hal Humphrey

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About the Cover: The Philippine eagle is among the largest three eagles in the world. It is a rare species, little known and hardly ever photographed.

This eagle is endemic to the Philippines—a country whose population is ever-growing while its forest areas have come down to a mere 5 percent of what originally covered the whole country. As the Philippine eagle can survive only in the rainforest, the situation for this species is most dramatic.

Klaus Nigge has been to the Philippines three times, where he visited people who are working hard to rescue this eagle. Joint efforts enabled him to find a pair of this species in one of the last remaining forest areas of Mindanao, where he spent several weeks up in the treetops to record how the eagles raised their young.

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- 1** Introduction to Biological Concepts and Research 1

Unit One Molecules and Cells

- 2** Life, Chemistry, and Water 22
- 3** Biological Molecules: The Carbon Compounds of Life 42
- 4** Energy, Enzymes, and Biological Reactions 71
- 5** The Cell: An Overview 90
- 6** Membranes and Transport 119
- 7** Cell Communication 141
- 8** Harvesting Chemical Energy: Cellular Respiration 161
- 9** Photosynthesis 182
- 10** Cell Division and Mitosis 205

Unit Two Genetics

- 11** Meiosis: The Cellular Basis of Sexual Reproduction 225
- 12** Mendel, Genes, and Inheritance 239
- 13** Genes, Chromosomes, and Human Genetics 261
- 14** DNA Structure, Replication, and Organization 286
- 15** From DNA to Protein 310
- 16** Regulation of Gene Expression 339
- 17** Bacterial and Viral Genetics 369
- 18** DNA Technologies: Analyzing and Modifying Genes 391
- 19** Genomes and Proteomes 416

Unit Three Evolutionary Biology

- 20** Development of Evolutionary Thought 439
- 21** Microevolution: Genetic Changes within Populations 456
- 22** Speciation 480
- 23** Paleobiology and Macroevolution 499
- 24** Systematics and Phylogenetics: Revealing the Tree of Life 528

Unit Four Biodiversity

- 25** The Origin of Life 553
- 26** Prokaryotes: Bacteria and Archaea 567
- 27** Protists 587
- 28** Seedless Plants 611

- 29** Seed Plants 630
- 30** Fungi 649
- 31** Animal Phylogeny, Acoelomates, and Protostomes 670
- 32** Deuterostomes: Vertebrates and Their Closest Relatives 706

Unit Five Plant Structure and Function

- 33** The Plant Body 748
- 34** Transport in Plants 774
- 35** Plant Nutrition 793
- 36** Reproduction and Development in Flowering Plants 811
- 37** Plant Signals and Responses to the Environment 838

Unit Six Animal Structure and Function

- 38** Introduction to Animal Organization and Physiology 867
- 39** Information Flow and the Neuron 883
- 40** Nervous Systems 903
- 41** Sensory Systems 921
- 42** The Endocrine System 943
- 43** Muscles, Bones, and Body Movements 966
- 44** The Circulatory System 981
- 45** Defenses against Disease 1002
- 46** Gas Exchange: The Respiratory System 1024
- 47** Animal Nutrition 1043
- 48** Regulating the Internal Environment 1069
- 49** Animal Reproduction 1096
- 50** Animal Development 1118

Unit Seven Ecology and Behavior

- 51** Ecology and the Biosphere 1145
- 52** Population Ecology 1172
- 53** Population Interactions and Community Ecology 1199
- 54** Ecosystems 1229
- 55** Biodiversity and Conservation Biology 1254
- 56** Animal Behavior 1278

Appendix A Answers A-1

Appendix B: Classification System A-36

Glossary G-1

Index I-1



Peter J. Russell received a B.Sc. in Biology from the University of Sussex, England, in 1968 and a Ph.D. in Genetics from Cornell University in 1972. He has been a member of the Biology faculty of Reed College since 1972 and is currently a professor of biology, emeritus. Peter taught a section of the introductory biology course, a genetics course, and a research literature course on molecular virology. In 1987 he received the Burlington Northern Faculty Achievement Award from Reed College in recognition of his excellence in teaching. Since 1986, he has been the author of a successful genetics textbook; current editions are *iGenetics: A Molecular Approach*, *iGenetics: A Mendelian Approach*, and *Essential iGenetics*. Peter's research was in the area of molecular genetics, with a specific interest in characterizing the role of host genes in the replication of the RNA genome of a pathogenic plant virus, and the expression of the genes of the virus; yeast was used as the model host. His research has been funded by agencies including the National Institutes of Health, the National Science Foundation, the American Cancer Society, the Department of Defense, the Medical Research Foundation of Oregon, and the Murdoch Foundation. He has published his research results in a variety of journals, including *Genetics*, *Journal of Bacteriology*, *Molecular and General Genetics*, *Nucleic Acids Research*, *Plasmid*, and *Molecular and Cellular Biology*. Peter has a long history of encouraging faculty research involving undergraduates, including cofounding the biology division of the Council on Undergraduate Research in 1985. He was Principal Investigator/Program Director of a National Science Foundation Award for the Integration of Research and Education (NSF-AIRE) to Reed College, 1998 to 2002.



Paul E. Hertz was born and raised in New York City. He received a B.S. in Biology from Stanford University in 1972, an A.M. in Biology from Harvard University in 1973, and a Ph.D. in Biology from Harvard University in 1977. While completing field research for the doctorate, he served on the Biology faculty of the University of Puerto Rico at Rio Piedras. After spending two years as an Isaac Walton Killam Postdoctoral Fellow at Dalhousie University, Paul accepted a teaching position at Barnard College, where he has taught since 1979. He was named Ann Whitney Olin Professor of Biology in 2000, and he received The Barnard Award for Excellence in Teaching in 2007. In addition to serving on numerous college committees, Paul chaired Barnard's Biology Department for eight years and served as Acting Provost and Dean of the Faculty from 2011 to 2012. He is the founding Program Director of the Hughes Science Pipeline Project at Barnard, an undergraduate curriculum and research program that has been funded continuously by the Howard Hughes Medical Institute since 1992. The Pipeline Project includes the Intercollegiate Partnership, a program for local community college students that facilitates their transfer to four-year colleges and universities. He teaches one semester of the introductory sequence for Biology majors and pre-professional students, lecture and laboratory courses in vertebrate zoology and ecology, and a year-long seminar that introduces first-year students to scientific research. Paul is an animal physiological ecologist with a specific research interest in the thermal biology of lizards. He has conducted fieldwork in the West Indies since the mid-1970s, most recently focusing on the lizards of Cuba. His work has been funded by the NSF, and he has published his research in such prestigious journals as *The American Naturalist*, *Ecology*, *Nature*, *Oecologia*, and *Proceedings of the Royal Society*. In 2010, he and his colleagues at three other universities received funding from NSF for a project designed to detect the effects of global climate warming on the biology of *Anolis* lizards in Puerto Rico.



Beverly McMillan has been a science writer for more than 25 years. She holds undergraduate and graduate degrees from the University of California, Berkeley, and is coauthor of a college text in human biology, now in its tenth edition. She has also written or coauthored numerous trade books on scientific subjects and has worked extensively in educational and commercial publishing, including eight years in editorial management positions in the college divisions of Random House and McGraw-Hill.

Welcome to the third edition of *Biology: The Dynamic Science*. The book's title reflects the speed with which our knowledge of biology is growing. Although biologists have made enormous progress in solving the riddles posed by the living world, every discovery raises new questions and provides new opportunities for further research. As in the prior two editions, we have encapsulated the dynamic nature of biology in the third edition by explaining biological concepts—and the data from which they are derived—in the historical context of each discovery and by describing what we know now and what new discoveries will be likely to advance the field in the future.

Building on a strong foundation . . .

The first two editions of this book provided students with the tools they need to learn fundamental biological concepts, processes, and facts. More important, they enabled students to think like scientists. Our approach encourages students to think about biological questions and hypotheses through clear examples of hypothesis development, observational and experimental tests of hypotheses, and the conclusions that scientists draw from their data. The many instructors and students who have used the book have generously provided valuable feedback about the elements that enhanced student learning. We have also received comments from expert reviewers. As a result of these inputs, every chapter has been revised and updated, and some units have been reorganized. In addition, the third edition includes new or modified illustrations and photos as well as some new features.

Emphasizing the big picture . . .

In this textbook, we have applied our collective experience as teachers, researchers, and writers to create a readable and understandable introduction that provides a foundation for students who choose to enroll in more advanced biology courses in the future. We provide straightforward explanations of fundamental concepts presented, where appropriate, from the evolutionary perspective that binds the biological sciences together. Recognizing that students in an introductory biology course face a potentially daunting amount of material, we strive to provide an appropriate balance between facts and concepts, taking great care to provide clear explanations while maintaining the narrative flow. In this way students not only see the big picture, but they understand how we achieved our present knowledge. Having watched our students struggle to navigate the many arcane details of college-level introductory biology, we constantly remind ourselves and each other to “include fewer facts, provide better explanations, and maintain the narrative flow,” thereby enabling students to see the big picture. Clarity of presentation,

thoughtful organization, a logical and seamless flow of topics within chapters, and carefully designed illustrations are key to our approach.

Focusing on research to help students engage the living world as scientists . . .

A primary goal of this book is to sharpen and sustain students' curiosity about biology, rather than dulling it with a mountain of disconnected facts. We can help students develop the mental habits of scientists and a fascination with the living world by conveying our passion for biological research. We want to excite students not only with *what biologists know* about the living world but also with *how they know it* and *what they still need to learn*. In doing so, we can encourage some students to accept the challenge and become biologists themselves, posing and answering important new questions through their own innovative research. For students who pursue other careers, we hope that they will leave their introductory—and perhaps only—biology course armed with intellectual skills that will enable them to evaluate future discoveries with a critical eye.

In this book, we introduce students to a biologist's “ways of knowing.” Research biologists constantly integrate new observations, hypotheses, questions, experiments, and insights with existing knowledge and ideas. To help students engage the world as biologists do, we must not simply introduce them to the current state of knowledge. We must also foster an appreciation of the historical context within which those ideas developed, and identify the future directions that biological research is likely to take.

To achieve these goals, our explanations are rooted in the research that established the basic facts and principles of biology. Thus, a substantial proportion of each chapter focuses on studies that define the state of biological knowledge today. When describing research, we first identify the hypothesis or question that inspired the work and then relate it to the broader topic under discussion. Our research-oriented theme teaches students, through example, how to ask scientific questions and pose hypotheses, two key elements of the scientific process.

Because advances in science occur against a background of research, we also give students a feeling for how biologists of the past formulated basic knowledge in the field. By fostering an appreciation of such discoveries, given the information and theories available to scientists in their own time, we can help students understand the successes and limitations of what we consider cutting edge today. This historical perspective also encourages students to view biology as a dynamic intellectual enterprise, not just a collection of facts and generalities to be memorized.

We have endeavored to make the science of biology come alive by describing how biologists formulate hypotheses and evaluate them using hard-won data; how data sometimes tell only part of a story; and how the results of studies often end up posing more questions than they answer. Although students might prefer simply to learn the “right” answer to a question, they must be encouraged to embrace “the unknown,” those gaps in knowledge that create opportunities for further research. An appreciation of what biologists do *not* yet know will draw more students into the field. And by defining *why* scientists do not understand interesting phenomena, we encourage students to think critically about possible solutions and to follow paths dictated by their own curiosity. We hope that this approach will encourage students to make biology a part of their daily lives by having informal discussions and debates about new scientific discoveries.

Presenting the story line of the research process . . .

In preparing this book, we developed several special features to help students broaden their understanding of the material presented and of the research process itself. A Visual Tour of these features and more begins on page xiii.

- The chapter openers, entitled *Why It Matters . . .*, are engaging, short vignettes designed to capture students’ imaginations and whet their appetites for the topic that the chapter addresses. In many cases, this feature tells the story of how a researcher or researchers arrived at a key insight or how biological research solved a major societal problem, explained a fundamental process, or elucidated a phenomenon. The *Why It Matters . . .* also provides a brief summary of the contents of the chapter.
- To complement this historical or practical perspective, each chapter closes with a brief essay entitled *Unanswered Questions*, prepared by an expert or experts in the field. These essays identify important unresolved issues relating to the chapter topic and describe cutting-edge research that will advance our knowledge in the future.
- Each chapter includes a short, boxed essay entitled *Insights from the Molecular Revolution*, which describes how molecular tools allow scientists to answer questions that they could not have posed even 30 years ago. Most *Insights* focus on a single study and include sufficient detail for its content to stand alone.
- Many chapters are further supplemented with one or more short, boxed essays involving three different aspects of research. *Focus on Basic Research* essays describe how research has provided understanding of basic biological principles. *Focus on Applied Research* essays describe research designed to solve practical problems in the world, such as those relating to health or the environment. *Focus on Model Research Organisms* essays introduce model research organisms—such

as *Escherichia coli*, *Drosophila*, *Arabidopsis*, *Caenorhabditis*, the mouse, and *Anolis*—and explain why they are used as subjects for in-depth analysis.

Three types of specially designed *research figures* provide more detailed information about how biologists formulate and test specific hypotheses by gathering and interpreting data. The research figures are listed on the endpapers at the back of the book.

- *Experimental Research* figures describe specific studies in which researchers used both experimental and control treatments—either in the laboratory or in the field—to test hypotheses or answer research questions by manipulating the system they studied.
- *Observational Research* figures describe specific studies in which biologists have tested hypotheses by comparing systems under varying natural circumstances.
- *Research Method* figures provide examples of important techniques, such as the scientific method, cloning a gene, DNA microarray analysis, plant cell culture, producing monoclonal antibodies, radiometric dating, and cladistic analysis. Each *Research Method* figure leads a student through the purpose of the technique and protocol and describes how scientists interpret the data it generates.

Integrating effective, high-quality visuals into the narrative . . .

Today’s students are accustomed to receiving ideas and information visually, making the illustrations and photographs in a textbook important. Our illustration program provides an exceptionally clear supplement to the narrative in a style that is consistent throughout the book. Graphs and anatomical drawings are annotated with interpretative explanations that lead students, step by step, through the major points they convey.

For the second edition, we undertook a rigorous review of all the art in the text. The publishing team identified the key elements of effective illustrations. In focus groups and surveys, instructors helped us identify the “Key Visual Learning Figures” covering concepts or processes that demand premier visual learning support. Each of these figures was critiqued by our Art Advisory Board to ensure its usability and accuracy. For the third edition, we again evaluated each illustration and photograph carefully and made appropriate changes to improve their use as teaching tools. New illustrations for the edition were created in the same style as existing ones.

For the third edition, important figures were developed as *Closer Look* figures; a Summary and a concluding *Think Like a Scientist* question are designed to enhance student learning. Many *Closer Look* figures involve key biological processes, such as meiosis, transcription, muscle contraction, the cohesion-tension mechanism of water transport in plants, ecological interactions between predators and prey, and the haplodiploidy genetic system in social insects.

Organizing chapters around important concepts . . .

As authors and college teachers, we understand how easily students can get lost within a chapter. When students request advice about how to read a chapter and learn the material in it, we usually suggest that, after reading each section, they pause and quiz themselves on the material they have just encountered. After completing all of the sections in a chapter, they should quiz themselves again, even more rigorously, on the individual sections and, most important, on how the concepts developed in the different sections fit together. Accordingly, we have adopted a structure for each chapter to help students review concepts as they learn them.

- The organization within chapters presents material in digestible sections, building on students' knowledge and understanding as they acquire it. Each major section covers one broad topic. Each subsection, titled with a declarative sentence that summarizes the main idea of its content, explores a narrower range of material.
- Whenever possible, we include the derivation of unfamiliar terms so that students will see connections between words that share etymological roots. Mastery of the technical language of biology will allow students to discuss ideas and processes precisely. At the same time, we have minimized the use of unnecessary jargon.
- *Study Break* questions follow every major section. These questions encourage students to pause at the end of a section and review what they have learned before going on to the next topic within the chapter. Short answers to these questions appear in an appendix.

Encouraging active learning, critical thinking, and self-assessment of learning outcomes . . .

The third edition of *Biology: The Dynamic Science* includes a new active learning feature, *Think Like a Scientist*, which is designed to help students think analytically and critically about research presented in the chapter. *Think Like a Scientist* questions appear at the ends of *Experimental Research* figures, *Observational Research* figures, *Closer Look* figures, *Insights from the Molecular Revolution* boxes, and *Unanswered Questions*.

The new edition also includes *Think Outside the Book*, an active learning feature introduced in the second edition. *Think Outside the Book* activities have been designed to encourage students to explore biology directly or through electronic resources. Students may engage in these activities either individually or in small groups.

Supplementary materials at the end of each chapter help students review the material they have learned, assess their understanding, and think analytically as they apply the principles

developed in the chapter to novel situations. Many end-of-chapter questions also serve as good starting points for class discussions or out-of-class assignments.

- *Review Key Concepts* provides a summary of important ideas developed in the chapter, referencing specific figures and tables in the chapter. These *Reviews* are no substitute for reading the chapter, but students may use them as a valuable outline of the material, filling in the details on their own.
- *Understand & Apply* includes five types of end-of-chapter questions and problems that focus on the chapter's factual content while encouraging students to apply what they have learned: (1) *Test Your Knowledge* is a set of 10 questions (with answers in an appendix) that focus on factual material; (2) *Discuss the Concepts* involves open-ended questions that emphasize key ideas, the interpretation of data, and practical applications of the material; (3) *Design an Experiment* questions help students hone their critical thinking skills by asking them to test hypotheses that relate to the chapter's main topic; (4) *Interpret the Data* questions help students develop analytical and quantitative skills by asking them to interpret graphical or tabular results of experimental or observational research experiments for which the hypotheses and methods of analysis are presented; and (5) *Apply Evolutionary Thinking* asks students to answer a question in relation to the principles of evolutionary biology.

Helping students master key concepts throughout the course . . .

Teachers know that student effort is an important determinant of student success. Unfortunately, most teachers lack the time to develop novel learning tools for every concept—or even every chapter—in an introductory biology textbook. To help address this problem, we are pleased to offer **Aplia for Biology**, an automatically graded homework management system tailored to this edition. For students, Aplia provides a structure within which they can expand their efforts, master key concepts throughout the course, and increase their success. For faculty, Aplia can help transform teaching and raise productivity by requiring more—and more consistent—effort from students without increasing faculty workloads substantially. By providing students with continuous exposure to key concepts and their applications throughout the course, Aplia allows faculty to do what they do best—respond to questions, lead discussions, and challenge the students.

We hope you agree that we have developed a clear, fresh, and well-integrated introduction to biology as it is understood by researchers today. Just as important, we hope that our efforts will excite students about the research process and the biological discoveries it generates.

New to This Edition

The enhancements we have made in the third edition of *Biology: The Dynamic Science* reflect our commitment to provide a text that introduces students to new developments in biology while fostering active learning and critical thinking. As a part of this effort, we have added *Closer Look* figures that integrate a major concept into a highlighted visual presentation. The key concept is stated briefly at the top, shown in detail through one or more illustrations, and summarized at the bottom. A *Think Like a Scientist* question invites students to apply the figure concept(s) to a related problem or issue. We have also incorporated *Think Like a Scientist* questions into *Insights from the Molecular Revolution* and *Unanswered Questions*, as well as into *Experimental Research* and *Observational Research* figures.

We have also made important changes in coverage to follow recent scientific advances. A new Chapter 19, Genomes and Proteomes, introduces methods of genomics and proteomics along with examples of new discoveries and insights. In addition, we now devote two chapters to plant diversity, discussing seedless plants in Chapter 28 and seed plants in Chapter 29. Finally, we've consolidated our treatment of animal behavior into a single Chapter 56 (Animal Behavior), which integrates various approaches to this subfield of biology. Beyond these major organizational changes, we have made numerous improvements to update and clarify scientific information and to engage students as interested readers and active learners, as well as responsive scientific thinkers. The following sections highlight some of the new content and organizational changes in this edition.

Unit One: Molecules and Cells

To make molecular and cellular processes easier to grasp, this unit incorporates explanatory material into many more illustrations. For example, in Chapter 3 (Biological Molecules: The Carbon Compounds of Life), Table 3.1 now presents more information on the roles of functional groups of organic molecules and a new Figure 3.3 clarifies the concept of stereoisomers. In Chapter 5 (The Cell: An Overview), we have combined the diagrams of animal and plant cells in Figure 5.9 and labeled functions of the organelles. In Chapter 8 (Harvesting Chemical Energy: Cellular Respiration), a new overview diagram of glycolysis (Figure 8.7) helps students understand basic concepts. Chapter 10 (Cell Division and Mitosis) features a new discussion and illustration of the tight pairing of chromatids (sister chromatid cohesion) during mitosis.

New references to molecular aspects of evolution have been integrated into Unit One chapters to emphasize evolution as the theme unifying the subfields of the biological sciences. For example, in Chapter 5 (The Cell: An Overview), the discussion of the mitochondrial matrix now highlights how equivalent

structures in bacteria led scientists to propose and develop the endosymbiotic theory. In Chapter 6 (Membranes and Transport), we point out that the close similarity of bilayer membranes in all cells—prokaryotic and eukaryotic—is evidence that the basic structure of membranes evolved during the earliest stages of life on Earth, and has been conserved ever since. In Chapter 9 (Photosynthesis), a new section, *Evolution of Photosynthesis and Cellular Respiration*, summarizes the evolutionary development of these processes.

Unit Two: Genetics

Chapter 11 (Meiosis: The Cellular Basis of Sexual Reproduction) includes fuller descriptions of homologous chromosomes and sex chromosomes. Extensive revision and expansion of Chapter 16 (Regulation of Gene Expression) provides more thorough coverage of gene regulation and the operon model. We now introduce the role of DNA-binding proteins in prokaryotic as well as eukaryotic gene regulation and include more detail on the activation of regulatory molecules. We have also added detail on combinatorial gene regulation, along with a figure showing a specific example, and have added new information and an illustration of how growth factors and growth-inhibiting factors affect cell division. Chapter 17 (Bacterial and Viral Genetics) includes new information on how horizontal gene transfer contributes to genome evolution in prokaryotes, and evidence of its possible contribution to eukaryotic genome evolution.

A new Chapter 19 (Genomes and Proteomes) focuses on the methods of genomics and the information it generates. This chapter describes how genome sequences are determined and annotated, how genes in genomes are identified and characterized, and how studies have generated new information on the evolution of genes and of genomes. It also includes examples of how genomics has become a source of new discoveries in many fields, including human physiology and evolutionary biology.

Unit Three: Evolutionary Biology

In Chapter 21 (Microevolution: Genetic Changes within Populations), *Observational Research* Figure 21.11 now shows more clearly how opposing forces of directional selection produce stabilizing selection. Plant speciation by allopolyploidy and polyploidy is shown in parallel illustrations in one figure (22.16), allowing easy comparison. In Chapter 23 (Paleobiology and Macroevolution), Figure 23.15 clarifies our understanding of the rise and fall of plant lineages through evolutionary time. Chapter 24 (Systematics and Phylogenetics: Revealing the Tree of Life) includes a new example of how systematists construct phylogenetic trees

with genetic distance data and includes a clarified discussion of statistical methods used to construct phylogenetic trees. Reworked phylogenetic trees throughout Chapter 24 are now fully consistent in presentation.

Unit Four: Biodiversity

In Chapter 26 (Prokaryotes: Bacteria and Archaea), a new *Insights from the Molecular Revolution* describes how changes in gene expression in the bacterium that causes gingivitis help govern its transition from a free-living state to a biofilm. A revised and expanded section discusses the five subgroups of proteobacteria. In Chapter 27 (Protists), we've added the nucleariids to the Opisthokont group, along with evidence that they may be more closely related to fungi than to animals.

Plant diversity is now covered in two chapters. Chapter 28 (Seedless Plants) describes trends in land plant evolution and the characteristics of bryophytes and seedless vascular plants, and Chapter 29 (Seed Plants) focuses on adaptations and distinguishing features of gymnosperms and flowering plants. Chapter 28 also includes a new *Unanswered Questions* essay, and Chapter 29 presents a new *Insights from the Molecular Revolution* feature on plant genome evolution. Chapter 30 (Fungi) presents an updated discussion of the evolution of multicellular animals and fungi from different opisthokont ancestors. Changes to Chapter 31 (Animal Phylogeny, Acoelomates, and Protostomes) include color-coding of anatomical illustrations of invertebrates to distinguish structures arising from endoderm, mesoderm, and ectoderm, and a new Table 31.1 providing a phylogenetic overview of the phyla presented in the chapter. In Chapter 32 (Deuterostomes: Vertebrates and Their Closest Relatives), a new *Insights from the Molecular Revolution* feature describes a study of the evolutionary gains and losses of genes that code for olfactory receptor proteins in various clades of mammals. Figure 32.38, which shows timelines for the species of hominins, has been updated with recently discovered fossils. The discussion of human evolution includes recent genomic studies of the relationship between Neanderthals and modern humans.

Unit Five: Plant Structure and Function

Chapter 33 (The Plant Body) features clearer illustrations of plant growth. Chapter 34 (Transport in Plants) has more focused discussions and illustrations of water movements in roots and the physiology of stomatal function. A new *Unanswered Questions* explores research in plant metabolomics. Chapter 36 (Reproduction and Development in Flowering Plants) includes

refined diagrams of floral whorls and self-incompatibility, an updated *Insights from the Molecular Revolution* on trichome development, and an updated *Experimental Research* figure on studies of floral organ identity genes. Chapter 37 (Plant Signals and Responses to the Environment) begins with a new *Why It Matters* essay presenting the diverse adaptations of creosote bush (*Larrea tridentata*) to environmental challenges such as extended drought. The chapter also has been reorganized, with the discussion of signal transduction pathways and second messenger systems now included in the introduction to plant hormones. New art illustrates current thinking on different signal transduction mechanisms in plant cells.

Unit Six: Animal Structure and Function

In Chapter 43 (Muscles, Bones, and Body Movements), a new *Insights from the Molecular Revolution* presents experiments on exercise training in racehorses. We have updated and clarified the discussion of immunity in Chapter 45 (Defenses against Disease) and added new material on how microbial pathogens are detected and how pathogens may sometimes escape recognition by the immune system. In Chapter 47 (Animal Nutrition), we have added detail on absorption in the small intestine. Chapter 48 (Regulating the Internal Environment) has expanded coverage of mammalian kidney function and the role of countercurrent heat exchanges in maintaining body temperature. In Chapter 50 (Animal Development), we have revised and expanded Section 50.5, The Cellular Basis of Development, including new information on apoptosis during development and on molecular mechanisms of induction.

Unit Seven: Ecology and Behavior

In Chapter 51 (Ecology and the Biosphere), improved illustrations clarify the effects of latitudinal and seasonal variations in incoming solar radiation. In Chapter 52 (Population Ecology), we have updated Figures 52.22 and 52.23 on human population growth. In Chapter 53 (Population Interactions and Community Ecology), we have improved Figure 53.22 showing the food web. We have also added informative labels to Figure 53.25, which shows the effects of storms on corals. Chapter 55 (Biodiversity and Conservation Biology) features a new Figure 55.16 illustrating the species–area relationship. A unified Chapter 56 (Animal Behavior) concludes the text, integrating the discussions of genetic and experiential bases of animal behavior, the neurophysiological and endocrinological control of specific behaviors, and the ecology and evolution of several broad categories of animal behavior.

THINK AND ENGAGE LIKE A SCIENTIST!

Develop a deep understanding of the core concepts in biology and build a strong foundation for future courses.



Welcome to **Biology: The Dynamic Science, Third Edition**, by Peter J. Russell, Paul E. Hertz, and Beverly McMillan. The authors convey their passion for biology as they guide you to an understanding of what scientists know about the living world, how they know it, and what they still need to learn. The pages that follow highlight a few of the many ways that they have made this book a great learning tool for you. You'll also find information about dynamic online resources, as well as print materials that will help you master key concepts and succeed in the course.

Determine which strand is which, and complete the blanks to identify them.

The following strand presents the sequence of the _____.

5'—G^{*}—GCCACC AUGGGACCC.....CCAUAG

nontemplate DNA
template DNA
mature mRNA

The following strand presents the sequence of the _____.

5'—TATAAAA...GCCACC ATGGGACCC.....CCATAG

The following strand presents the sequence of the encoded polypeptide.

N terminus —Met AA₂ AA₃ AA_n

The following strand presents the sequence of the _____.

3'—ATATTTT...CGGTGG TACCTGGG.....GGTATC

The blue-colored region is the _____.

The following image shows daytime temperatures at every location on Earth except for Antarctica, averaged over every day in May 2009. These measurements were made by a sensor aboard NASA's Aqua satellite.

From this view, you can see that temperatures remain constant when traveling along the same _____.

The optimal body temperature of a white mouse (*Peromyscus leucopus*) is approximately 37°C. If this species were unable to regulate its body temperature, it would most likely be found at _____ latitude or at _____ altitude.

The most reason that the average temperature is lower at the poles is the _____.

The U.S. government also maintains a network of ground climate monitoring stations throughout the world. These stations provide more specific local climate information. For example, consider the following annual averages from two different climate stations in the Americas.

Climate Station 1

Month	1	2	3	4	5	6	7	8	9	10	11	12
Precipitation (mm)	100	100	100	100	100	100	100	100	100	100	100	100
Temperature (degrees Celsius)	10	10	10	10	10	10	10	10	10	10	10	10

Climate Station 2

Month	1	2	3	4	5	6	7	8	9	10	11	12
Precipitation (mm)	100	100	100	100	100	100	100	100	100	100	100	100
Temperature (degrees Celsius)	10	10	10	10	10	10	10	10	10	10	10	10

Climate Station Key

- Precipitation, millimeters
- Temperature, degrees Celsius

See regional weather facts (2004-2005)

Which of these two climate stations is located in the Southern Hemisphere?

Climate Station 2

Climate Station 1

◀ **Aplia for Biology**, an interactive online tool that complements the text and helps you learn and understand key concepts through focused assignments, an engaging variety of problem types, exceptional text/art integration, and immediate feedback.

A BIG PICTURE FOCUS

Straightforward explanations of fundamental concepts bind the biological sciences together and enable you to see the big picture. Easy-to-use learning tools point out the topics covered in each chapter, show why they are important, and help you learn the material.

22



Two closely related bird species, purple martins (*Progne subis*) and tree swallows (*Tachycineta bicolor*) perching together on a branch in Crane Creek, Ohio.

STUDY OUTLINE

- 22.1 What Is a Species?
- 22.2 Maintaining Reproductive Isolation
- 22.3 The Geography of Speciation
- 22.4 Genetic Mechanisms of Speciation

Speciation



FIGURE 22.1 Birds of paradise. A male Count Raggi's bird of paradise (*Paradisaea raggiana*) tries to attract the attention of a female (not pictured) with his showy plumage and conspicuous display. There are 43 known bird of paradise species, 35 of them found only on the island of New Guinea.

Why it matters . . . In 1927, nearly 100 years after Darwin boarded the *Beagle*, a young German naturalist named Ernst Mayr embarked on his own journey, to the highlands of New Guinea. He was searching for rare “birds of paradise” (Figure 22.1). These birds were known in Europe only through their ornate and colorful feathers, which were used to decorate ladies’ hats. On his trek through the remote Arfak Mountains, Mayr identified 137 bird species (including many birds of paradise) based on differences in their size, plumage, color, and other external characteristics.

To Mayr’s surprise, the native Papuans—who were untrained in the ways of Western science, but who hunted these birds for food and feathers—had their own names for 136 of the 137 species he had identified. The close match between the two lists confirmed Mayr’s belief that the *species* is a fundamental level of organization in nature. Each species has a unique combination of genes underlying its distinctive appearance and habits. Thus, people who observe them closely—whether indigenous hunters or Western scientists—can often distinguish one species from another.

Mayr also discovered some remarkable patterns in the geographical distributions of the bird species in New Guinea. For example, each mountain range he explored was home to some species that lived nowhere else. Closely related species often lived on different mountaintops, separated by deep valleys of unsuitable habitat. In 1942, Mayr published the book *Systematics and the Origin of Species*, in which he described the role of geography in the evolution of new species; the book quickly became a cornerstone of the modern synthesis (which was outlined in Section 20.3).

480

➤ **Study Break** sections encourage you to pause and think about the material you have just encountered before moving to the next section.

STUDY BREAK 22.1

1. How do the morphological, biological, and phylogenetic species concepts differ?
2. What is clinal variation?

◀ **Study Outline** provides an overview of main chapter topics and key concepts. Each section breaks the material into a manageable amount of information, so you can develop understanding as you acquire knowledge.

◀ **Why It Matters** sections at the beginning of each chapter capture the excitement of biology and help you understand why the topic is important and how the material that follows fits into the big picture.

Your study of biology focuses not only on **what** scientists know about the living world but also **how** they know it. Use these unique features to learn how scientists ask scientific questions, pose hypotheses, and test them.

NEW!

➤ **“Think Like a Scientist”** questions ask you to apply what you have learned beyond the material presented in the text. These questions are incorporated into *Experimental Research*, *Observational Research*, and *Closer Look* figures, as well as into *Insights from the Molecular Revolution* and *Unanswered Questions* boxes.

FIGURE 12.5 Experimental Research

The Principle of Segregation: inheritance of Flower Color in Garden Peas

Question: How is flower color in garden peas inherited?

Experiment: Mendel created a true-breeding purple-flowered plant and analyzed the progeny through the P , F_1 , and F_2 generations. The P plant has two recessive alleles.

1 P generation: A true-breeding purple-flowered plant (PP) is crossed with a true-breeding white-flowered plant (pp). The P generation produces gametes with the P allele and the p allele. The plant is homozygous for the P allele.

2 Haploid gametes: The gametes are P and p from the purple parent, and p and p from the white parent.

3 F₁ generation: All offspring are purple-flowered (Pp). The gametes from the P parent are P and p. The gametes from the p parent are p and p.

4 F₂ generation: The F_1 plants (Pp) are selfed. The gametes are P and p from both parents. The F_2 generation produces purple (PP) and white (pp) flowers. The ratio is 3 purple to 1 white.

THINK LIKE A SCIENTIST Suppose you pick at random one of the F_2 purple-flowered plants and allow it to self. What is the chance that the progeny will include both purple-flowered and white-flowered plants?

INSIGHTS FROM THE Molecular Revolution

Hot Potatoes: Do plants use uncoupling proteins to generate heat?

Key Concepts: Mitochondria use several biochemical and molecular processes to make ATP. One process is uncoupling the respiratory chain from ATP production. This process is called uncoupling protein (UCP). UCPs allow the mitochondrial membrane to be more permeable to protons, which reduces the proton gradient and the energy available to drive ATP synthesis.

Research Question: Do plants use UCPs to generate heat?

Experiments: Research by Marlene Lohr and her colleagues at the Max Planck Institute for Molecular Plant Physiology in Germany shows that some leaves in plants can use the same process involving UCPs to generate heat. They discovered two types of UCPs.

Figure 1: UCP mRNA levels of activity. Shows a plant with high UCP mRNA levels in leaves and roots, and low levels in stems.

Figure 2: Heat is a response to a cold exposure. Shows that UCP mRNA levels increase in leaves and roots when a plant is exposed to cold.

Figure 3: Heat is a response to a cold exposure. Shows that UCP mRNA levels increase in leaves and roots when a plant is exposed to cold.

➤ **Insights from the Molecular Revolution** essays highlight how molecular technologies allow researchers to answer questions that they could not even pose 20 or 30 years ago.

UNANSWERED QUESTIONS

What is the role of uncoupling proteins (UCPs) in plants? UCPs are found in the mitochondrial membrane and are thought to be involved in heat production. However, their exact function in plants is still unknown.

How do mitochondrial proteins change in relation to Alzheimer's disease? Mitochondrial proteins are involved in energy production and cellular signaling. In Alzheimer's disease, these proteins may be altered, leading to mitochondrial dysfunction.

What is the role of UCPs in plants? UCPs are found in the mitochondrial membrane and are thought to be involved in heat production. However, their exact function in plants is still unknown.

➤ **Unanswered Questions** explore important unresolved issues identified by experts in the field and describe cutting-edge research that will advance our knowledge in the future.

FOCUS ON Applied Research

Malaria and the Plasmodium Life Cycle

Key Concepts: Malaria is a parasitic disease caused by Plasmodium species. The life cycle involves the parasite developing in a mosquito and then being transmitted to a new human host.

Figure 1: Life cycle of a Plasmodium species that causes malaria. Shows the stages from zygote to gametocyte in the mosquito, and from gametocyte to zygote in the human host.

Figure 2: Malaria and the Plasmodium Life Cycle. Shows the stages from zygote to gametocyte in the mosquito, and from gametocyte to zygote in the human host.

Figure 3: Malaria and the Plasmodium Life Cycle. Shows the stages from zygote to gametocyte in the mosquito, and from gametocyte to zygote in the human host.

➤ **Focus on Research** boxes present research topics in more depth.

➤ **Focus on Applied Research** describes how scientific research has solved everyday problems.

➤ **Focus on Basic Research** describes seminal research that provided insight into an important problem.

➤ **Focus on Model Research Organisms** explains why researchers use certain organisms as research subjects.

ENGAGE LIKE A SCIENTIST

Be Active. Get involved in the process of learning and doing biology.

► **Research Figures** provide information about how biologists formulate and test specific hypotheses by gathering and interpreting data.

Observational Research

FIGURE 22.18 Observational Research

Chromosomal Similarities and Differences among the Great Apes

Question Does chromosome structure differ between humans and their closest relatives among the apes?

Hypothesis Large scale chromosome rearrangements contributed to the development of reproductive isolates on between species within the evolutionary clade that includes humans and apes.

Prediction Chromosome structure differs markedly between humans and their close relatives among the great apes: chimpanzees, gorillas, and orangutans.

Method Jorge Yun and Om Prakash of the University of Minnesota Medical School used Giemsa stain to visualize the banding patterns on metaphase chromosome preparations from humans, chimpanzees, gorillas, and orangutans. They identified about 1,000 bands that are present in the four species. They then searched for similarities and differences.

Results Analysis of human chromosome 2 reveals that it was produced by the fusion of two smaller chromosomes from other three species. A change in the position of the centromere in human chromosome 2 matches that of chimpanzees, gorillas, and orangutans. It falls within an inverted segment of the chromosome.

Conclusion Differences in chromosome structure between humans and both gorillas and orangutans are humans and chimpanzees. Structural differences in the chromosomes of these four species may contribute to reproductive isolation.

Experimental Research

FIGURE 14.9 Experimental Research

The Meselson and Stahl Experiment
Demonstrating the Semiconservative Model for DNA Replication to Be Correct

Question Does DNA replicate semiconservatively?

Experiment Matthew Meselson and Franklin Stahl proved that the semiconservative model of DNA replication was correct and that the conservative and dispersive models were incorrect.

1 Bacteria were grown in ^{15}N (heavy) medium. The heavy isotope is incorporated in the base of DNA, resulting in a DNA being heavy that is labeled with ^{15}N .

2 Bacteria transfer into ^{14}N (light) medium and allowed to grow and divide for several generations. A first DNA is light.

3 DNA extracted from bacteria cultured in ^{14}N medium and after each generation in ^{14}N medium. Extracted DNA was centrifuged in a special solution to separate DNA of different densities.

Results Meselson and Stahl obtained the following results:

Conclusion The predicted DNA banding patterns for the three models are shown in Figure 14.8. The results support the semiconservative model.

Model	1st Generation	2nd Generation
Semiconservative	Hybrid DNA	Hybrid DNA and All-14N DNA
Conservative	All-15N DNA and All-14N DNA	All-15N DNA and All-14N DNA
Dispersive	Hybrid DNA	Hybrid DNA

FIGURE 10.7 Research Method

Preparing a Human Karyotype

Purpose A karyotype is a display of chromosomes of an organism arranged in pairs. A normal karyotype has a characteristic appearance for each species. Examination of the karyotype of the chromosomes from a particular individual indicates whether the individual has a normal set of chromosomes or whether there are abnormalities in number or appearance of individual chromosomes. A normal karyotype can be used to indicate the species.

Protocol

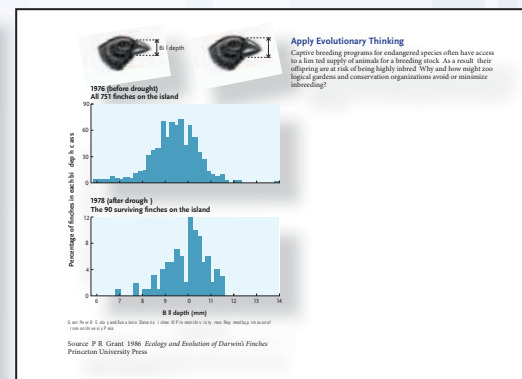
- 1 Add sample to culture medium that has stimulator for growth and division of cells (white blood cells in the case of blood). Incubate at 37°C. Add colchicine which blocks the formation of microtubules. As a result, the spindle does not form and this causes mitosis to arrest at metaphase.
- 2 Stain the cells so that the chromosomes are distinguishable. Some stains produce chromosome specific banding patterns as shown in the photograph below.

Results The karyotype is evaluated with respect to the being asked. For example, I may identify a particular karyotype whether or not the chromosome set of a human is normal or aberrant.

► **Interpret the Data** exercises, drawn from published biological research, help you build your skills in analyzing figures and reading graphs or tables.

Interpret the Data

Peter and Rosemary Grant of Princeton University have studied the ecology and evolution of finches on the Galapagos Islands since the early 1970s. They have shown that finches with large bills (as measured by bill depth; see **Figure**) can eat both small seeds and large seeds, but finches with small bills can only eat small seeds. In 1977, a severe drought on the island of Daphne Major reduced seed production by plants. After the birds consumed whatever small seeds they found, only large seeds were still available. The resulting food shortage killed a majority of the medium ground finches (*Geospiza fortis*) on Daphne Major; their population plummeted from 751 in 1976 to just 90 in 1978. The Grants' research also documented a change in the distributions of bill depths in the birds from 1976 to 1978, as illustrated in the graphs to the right. In light of what you now know about the relationship between bill size and food size for these birds, interpret the change illustrated in the graph. What type of natural selection does this example illustrate?



► **Think Outside the Book** activities help you think analytically and critically as you explore the biological world, either on your own or as part of a team.

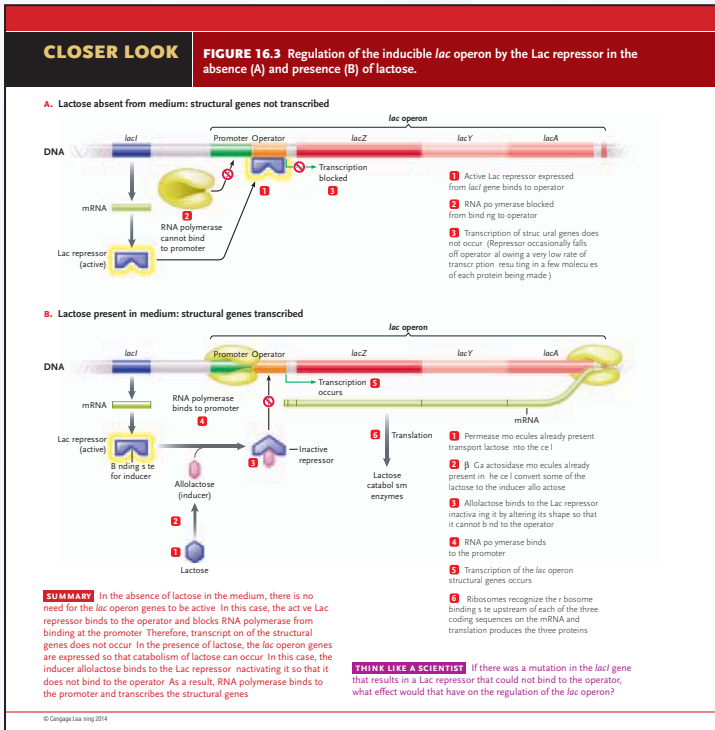
THINK OUTSIDE THE BOOK

Earlier in the chapter we mentioned the fact that cloned animals may have many genes whose expression is abnormal compared to gene expression in a noncloned animal. Individually or collaboratively, outline the steps you would take experimentally to determine, on a genome-wide scale, if gene are abnormally expressed in a cloned mammal. Your answer should include how the experiment reveals both qualitative and quantitative differences in gene expression.

THINK OUTSIDE THE BOOK

Access the web page for the Tree of Life project at <http://www.tolweb.org/tree/>. Select a group of animals or plants that is of interest to you, and study the structure of its phylogenetic tree. How many major clades does it include? On the basis of what shared derived characters are those clades defined?

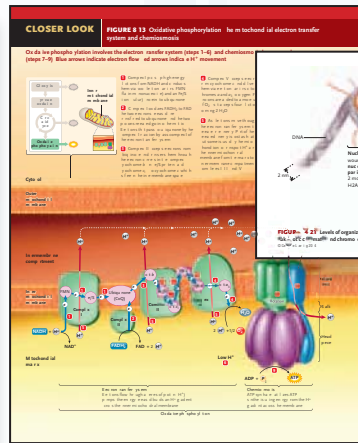
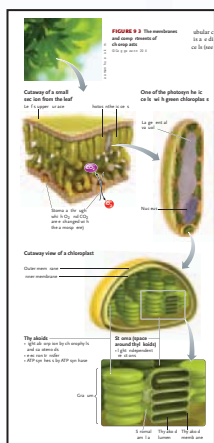
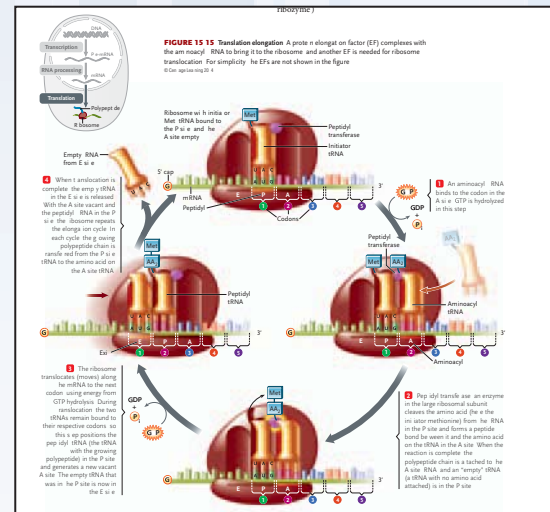
Spectacular illustrations—developed with great care—help you visualize biological processes, relationships, and structures.



NEW!

“Closer Look” figures help you gain a better understanding of a major concept through a visual presentation, usually a detailed, multistep diagram. The figures end with a *Summary* and a *Think Like a Scientist* question.

Illustrations of complex biological processes are annotated with *numbered step-by-step explanations* that lead you through all the major points. Orientation diagrams are inset on figures and help you identify the specific biological process being depicted and where the process takes place.



Macro-to-Micro views help you visualize the levels of organization of biological structures and how systems function as a whole.

End-of-chapter material encourages you to review, assess your understanding, think analytically, and apply what you have learned to novel situations.

➤ **Review Key Concepts** provides an outline summary of important ideas developed in the chapter and references the chapter's figures and tables.

REVIEW KEY CONCEPTS

To access the course materials and companion resources for this text, please visit www.engagebrain.com.

18.1 DNA Cloning

- Producing multiple copies of genes by cloning is a common first step for studying the structure and function of genes, or for manipulating genes. Cloning involves cutting genomic DNA and a cloning vector with the same restriction enzyme, joining the fragments to produce recombinant plasmids, and introducing those plasmids into a living cell such as a bacterium, where replication of the plasmid takes place (Figures 18.1–18.3).
- A clone containing a gene of interest may be identified among a population of clones by using DNA hybridization with a labeled nucleic acid probe (Figure 18.5).
- A genomic library is a collection of clones that contains a copy of every DNA sequence in the genome. A cDNA (complementary DNA) library is the entire collection of cloned cDNAs made from the mRNAs isolated from a cell. A cDNA library contains only sequences from the genes that are active in the cell when the mRNAs are isolated.

18.2 Applications of DNA Technologies

- Recombinant DNA and PCR techniques are used in DNA molecular testing for human genetic disease mutations. One approach exploits restriction site differences between normal and mutant alleles of a gene that create restriction fragment length polymorphisms (RFLPs) which are detectable by DNA hybridization with labeled nucleic acid probe (Figures 18.8 and 18.9).
- Human DNA fingerprints are produced from a number of loci in the genome characterized by short, tandemly repeated sequences that vary in number in all individuals (except identical twins). To produce a DNA fingerprint, the PCR is used to amplify the region of genomic DNA for each locus, and the lengths of the PCR products indicate the alleles an individual has for the repeated sequences at each locus. DNA fingerprints are widely used to establish paternity, ancestry, or criminal guilt (Figure 18.10).
- Genetic engineering is the introduction of new genes or genetic information to alter the genetic makeup of humans, other animals, plants, and microorganisms such as bacteria and yeast. Genetic engineering primarily aims to correct hereditary defects, improve domestic animals and crop plants, and provide proteins for medicine, research, and other applications (Figures 18.11–18.13 and 18.15).
- Genetic engineering has enormous potential for research and applications in medicine, agriculture, and industry. Potential risks include unintended damage to living organisms or to the environment.

Animation: How Dolly was created

Animation: DNA fingerprinting

Animation: Transferring genes into plants

UNDERSTAND & APPLY

Test Your Knowledge

- A complementary DNA library (cDNA) and a genomic library are similar in that both
 - use bacteria to make eukaryotic proteins
 - provide information on whether genes are active
 - contain all of the DNA of an organism cut into pieces
 - clone mRNA
 - depend on cloning in a living cell to produce multiple copies of the DNA of interest
- Why do the cDNA libraries produced from two different cell types in the human body often contain different cDNAs?
 - Because different expression vectors must be used to insert cDNAs into different cell types
 - Because different cell types contain different numbers of chromosomes
 - Because different cell types contain different genomic DNA sequences
 - Because different genes are transcribed in different cell types
 - Because different cell types contain different restriction enzymes
- The point at which a restriction enzyme cuts DNA is determined by
 - the sequence of base-pair
 - the length of the DNA molecule
 - whether it is closer to the 5' end or 3' end of the DNA molecule
 - the number of copies of the DNA molecule in a bacterial cell
 - the location of a start codon in a gene
- Restriction endonucleases ligase plasmids. *E. coli* electrophoretic gels and a bacterial gene resistant to an antibiotic are all required for
 - diodeoxyribonucleotide acid synthesis
 - PCR
 - DNA cloning
 - DNA fingerprinting
 - DNA sequencing
- After a polymerase chain reaction (PCR) agarose gel electrophoresis is often used to
 - amplify the DNA
 - convert cDNA into genomic DNA
 - convert cDNA into messenger RNA
 - verify that the desired DNA sequence has been amplified
 - synthesize primer DNA molecules
- Restriction fragment length polymorphisms (RFLPs)
 - are produced by reaction with restriction endonucleases and are detected by Southern blot analysis
 - are of the same length for mutant and normal β globin alleles
 - determine the sequence of bases in a DNA fragment
 - have in their middle short fragments of DNA that are palindromic
 - are used as vectors
- DNA fingerprinting, which is often used in forensics paternity testing and for establishing ancestry
 - compares one stretch of the same DNA between two or more people
 - measures different lengths of DNA from many repeating noncoding regions
 - requires the largest DNA lengths to run the greatest distance on a gel
 - requires amplification after the gels are run
 - can easily differentiate DNA between identical twins
- Which of the following is needed both in using bacteria to produce proteins and in genetic engineering of human cells?
 - DNA fingerprinting based on microsatellite sequences
 - insertion of a transgene into an expression vector
 - restriction fragment length polymorphism (RFLP)
 - screening of a cDNA library by DNA hybridization
 - antibiotic resistance
- Dolly the sheep was an example of reproductive (germ line) cloning. Required to perform this process was
 - implantation of uterine cells from one strain into the mammary gland of another
 - fusion of the mammary cell from one strain with an enucleated egg of another strain
 - fusion of an egg from one strain with the egg of a different strain
 - fusion of an embryonic diploid cell with an adult haploid cell
 - fusion of two nucleated mammary cells from two different strains
- Which of the following is not true of somatic cell gene therapy?
 - White blood cells can be used
 - Somatic cells are cultured and the desired DNA is introduced into them
 - Cells with the introduced DNA are returned to the body
 - The technique is still very experimental
 - The inserted genes are passed to the offspring

➤ **Understand & Apply** end-of-chapter questions focus on both factual and conceptual content in the chapter while encouraging you to apply what you have learned.

Apply Evolutionary Thinking

In PCR, researchers use a heat-stable form of DNA polymerase from microorganisms that are able to grow in extremely high temperatures. Given what you learned in Chapter 3 about protein folding, and in Chapter 4 about the effects of temperature on enzymes, would you predict that the amino acids of heat-stable DNA polymerase enzymes would have evolved so they can form stronger chemical attractions with each other, or weaker chemical attractions? Explain your answer.

➤ **Apply Evolutionary Thinking** asks you to interpret a relevant topic in relation to the principles of evolutionary thinking.

Design an Experiment

Suppose a biotechnology company has developed a GMO, a transgenic plant that expresses *Bt* toxin. The company sells its seeds to a farmer under the condition that the farmer may plant the seed, but not collect seed from the plants that grow and use it to produce crops in the subsequent season. The seeds are expensive, and the farmer buys seeds from the company only once. How could the company show experimentally that the farmer has violated the agreement and is using seeds collected from the first crop to grow the next crop?

➤ **Design an Experiment** challenges your understanding of the chapter and helps you deepen your understanding of the scientific method as you consider how to develop and test hypotheses about a situation that relates to a main chapter topic.

Discuss the Concepts

- What should juries know to be able to interpret DNA evidence? Why might juries sometimes ignore DNA evidence?
- A forensic scientist obtained a small DNA sample from a crime scene. In order to examine the sample, he increased its quantity by cycling the sample through the polymerase chain reaction. He estimated that there were 50,000 copies of the DNA in his original sample. Derive a simple formula and calculate the number of copies he will have after 15 cycles of the PCR.

➤ **Discuss the Concepts** enables you to participate in discussions on key questions to build your knowledge and learn from others.

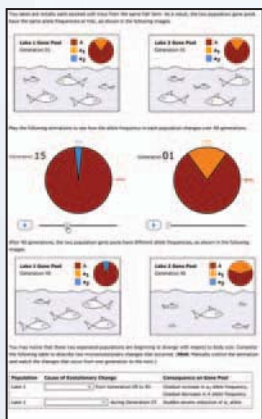
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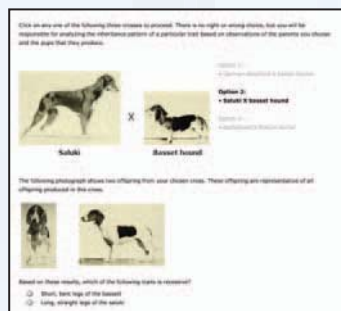
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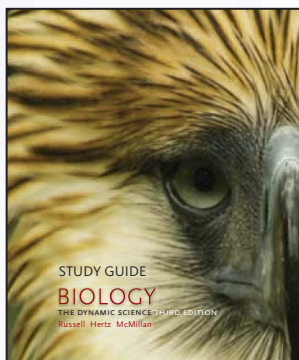
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We would also like to thank our advisors and contributors:

Supplements Authors

David Asch, *Youngstown State University*
Carolyn Bunde, *Idaho State University*
Albia Duggar, *Miami Dade College*
Frederick B. Essig, *University of South Florida*
Brent Ewers, *University of Wyoming*
Anne Galbraith, *University of Wisconsin–LaCrosse*
Alan Hecht, *Hofstra University*
Kathleen Hecht, *Nassau Community College*
Qinzi Ji, *Instructional Curriculum Specialist*
William Kroll, *Loyola University Chicago–Lake Shore*
Todd Osmundson, *University of California, Berkeley*
Debra Pires, *University of California, Los Angeles*
Elena Pravosudova, *University of Reno, Nevada*
Jeff Roth-Vinson, *Cottage Grove High School*
Mark Sheridan, *North Dakota State University*
Gary Shin, *California State University, Long Beach*
Michael Silva, *El Paso Community College*
Michelle Taliaferro, *Auburn University, Montgomery*
Jeffrey Taylor, *State University of New York, Canton*
Catherine Anne Ueckert, *Northern Arizona University*
Jyoti Wagle, *Houston Community College, Central College*
Alexander Wait, *Missouri State University*

Media and Aplia for Biology Reviewers and Class Testers

Thomas Abbott, *University of Connecticut*
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Gerald Bergtrom, *University of Wisconsin–Milwaukee*

Scott Bowling, *Auburn University*
Joi Braxton-Sanders, *Northwest Vista College*
Carolyn Bunde, *Idaho State University*
Jung H. Choi, *Georgia Institute of Technology*
Tim W. Christensen, *East Carolina University*
Patricia J. S. Colberg, *University of Wyoming*
Robin Cooper, *University of Kentucky*
Karen Curto, *University of Pittsburgh*
Joe Demasi, *Massachusetts College of Pharmacy and Health Science*
Nicholas Downey, *University of Wisconsin–LaCrosse*
Albia Dugger, *Miami-Dade College*
Natalie Dussourd, *Illinois State University*
Lisa Elfring, *University of Arizona*
Bert Ely, *University of South Carolina*
Kathleen Engelmann, *University of Bridgeport*
Helene Engler, *Science Writer*
Monika Espinasa, *State University of New York at Ulster*
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Nathan Lents, *John Jay College*

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Brad Mehrtens, *University of Illinois at Urbana-Champaign*
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Michael Reagan, *College of Saint Benedict and Saint John's University*
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Reviewers and Contributors

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Broward Community College-North
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University of North Dakota
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North Harris Montgomery Community College
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Christine Case, *Skyline College*
Domenic Castignetti,
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Kent Christensen,
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Deborah Athas Dardis,
Southeastern Louisiana University
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California State University, Fullerton
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University of Illinois at Urbana-Champaign
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University of Wisconsin-LaCrosse
Gordon Patrick Duffie,
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University of Bridgeport
Helene Engler, *Science Consultant and Lecturer*
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Judith Goodenough,
University of Massachusetts Amherst
H. Maurice Goodman, *University of
Massachusetts Medical School*

Bruce Grant, *College of William and Mary*

Becky Green-Marroquin,
Los Angeles Valley College

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Katharine B. Gregg,
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Jennifer Jeffery,
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Eric Jellen, *Brigham Young University*

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Virginia Commonwealth University

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Greg Keller,
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Bryce Kendrick, *University of Waterloo*

Bretton Kent, *University of Maryland*

Jack L. Keyes, *Linfield College Portland Campus*

David Kiewlich,
Science Consultant and Research Biologist

Scott L. Kight, *Montclair State University*

John Kimball, *Tufts University*

Hillar Klandorf, *West Virginia University*

Michael Klymkowsky,
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Loren Knapp, *University of South Carolina*

Richard Knapp, *University of Houston*

David Kooyman, *Brigham Young University*

Olga Ruiz Kopp, *Utah Valley State University*

Ana Koshy,
Houston Community College–Northwest

Donna Koslowsky, *Michigan State University*

Kari Beth Krieger,
University of Wisconsin–Green Bay

David T. Krohne, *Wabash College*

William Kroll,
Loyola University Chicago–Lake Shore

Josepha Kurdziel, *University of Michigan*

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Kathleen Marrs, *Indiana University–
Purdue University Indianapolis*

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California State University, Northridge

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Andrew G. McCubbin,
Washington State University

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Jacqueline S. McLaughlin,
Penn State University–Lehigh Valley

F. M. Anne McNabb, *Virginia Polytechnic
Institute and State University*

Mark Meade, *Jacksonville State University*

Bradley Mehrten,
University of Illinois at Urbana-Champaign

Amee Mehta, *Seminole State University*

Michael Meighan,
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Richard Merritt, *Houston Community College*

Jennifer Metzler, *Ball State University*

Ralph Meyer, *University of Cincinnati*

Melissa Michael,
University of Illinois at Urbana-Champaign

James E. “Jim” Mickle,
North Carolina State University

Hector C. Miranda, Jr.,
Texas Southern University

Jasleen Mishra,
Houston Community College–Southwest

Jeanne M. Mitchell, *Truman State University*

David Mohrman,
University of Minnesota Medical School Duluth

John M. Moore, *Taylor University*

Roderick M. Morgan,
Grand Valley State University

David Morton, *Frostburg State University*

Alexander Motten, *Duke University*

Alan Muchlinski,
California State University, Los Angeles

Michael Muller,
University of Illinois at Chicago

Richard Murphy, *University of Virginia*

Darrel L. Murray,
University of Illinois at Chicago

Allan Nelson, *Tarleton State University*

David H. Nelson, *University of South Alabama*

Jacalyn Newman, *University of Pittsburgh*

David O. Norris, *The University of Colorado*

Bette Nybakken, *Hartnell College*

Victoria Ochoa, *El Paso Community College, Rio
Grande Campus*

Tom Oeltmann, *Vanderbilt University*

Bruce F. O'Hara, *University of Kentucky*

Diana Oliveras,
The University of Colorado at Boulder

Alexander E. Olvido,
Virginia State University

Todd W. Osmundson,
University of California, Berkeley

Robert Osuna,
State University of New York, Albany

Karen Otto, *The University of Tampa*

William W. Parson,
University of Washington School of Medicine

James F. Payne, *The University of Memphis*

Craig Peebles, *University of Pittsburgh*

- Joe Pelliccia**, *Bates College*
- Kathryn Perez**,
University of Wisconsin–LaCrosse
- Vinnie Peters**,
Indiana University–Purdue University Fort Wayne
- Susan Petro**, *Ramapo College of New Jersey*
- Debra Pires**,
University of California, Los Angeles
- Jarmila Pittermann**,
University of California, Santa Cruz
- Thomas Pitzer**, *Florida International University*
- Roberta Pollock**, *Occidental College*
- Steve Vincent Pollock**,
Louisiana State University
- Elena Pravosudova**,
University of Nevada, Reno
- Jerry Purcell**, *San Antonio College*
- Jason M. Rauceo**,
John Jay College of Criminal Justice
- Kim Raun**, *Wharton County Junior College*
- Michael Reagan**, *College of Saint Benedict
and Saint John's University*
- Tara Reed**, *University of Wisconsin–Green Bay*
- Melissa Murray Reedy**,
University of Illinois at Urbana-Champaign
- Lynn Robbins**, *Missouri State University*
- Carolyn Roberson**,
Roane State Community College
- Laurel Roberts**, *University of Pittsburgh*
- George R. Robinson**,
State University of New York, Albany
- Kenneth Robinson**, *Purdue University*
- Frank A. Romano**,
Jacksonville State University
- Michael R. Rose**,
University of California, Irvine
- Michael S. Rosenzweig**, *Virginia Polytechnic
Institute and State University*
- Linda S. Ross**, *Ohio University*
- Ann Rushing**, *Baylor University*
- Scott D. Russell**, *University of Oklahoma*
- Linda Sabatino**, *Suffolk Community College*
- Tyson Sacco**, *Cornell University*
- Peter Sakaris**,
Southern Polytechnic State University
- Frank B. Salisbury**, *Utah State University*
- Mark F. Sanders**,
University of California, Davis
- Stephen G. Saupe**, *College of Saint Benedict and
Saint John's University*
- Andrew Scala**, *Dutchess Community College*
- John Schiefelbein**, *University of Michigan*
- Deemah Schirf**,
The University of Texas at San Antonio
- Kathryn J. Schneider**,
Hudson Valley Community College
- Jurgen Schnermann**, *University of Michigan
Medical School*
- Thomas W. Schoener**,
University of California, Davis
- Brian Shea**, *Northwestern University*
- Mark Sheridan**, *North Dakota State University*
- Dennis Shevlin**, *The College of New Jersey*
- Rebecca F. Shipe**,
University of California, Los Angeles
- Nancy N. Shontz**,
Grand Valley State University
- Richard Showman**,
University of South Carolina
- Jennifer L. Siemantel**, *Cedar Valley College*
- Michael Silva**, *El Paso Community College*
- Bill Simcik**, *Lone Star College–Tomball*
- Robert Simons**,
University of California, Los Angeles
- Roger Sloboda**, *Dartmouth College*
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- Christine C. Spencer**,
Georgia Institute of Technology
- Bruce Stallsmith**,
The University of Alabama in Huntsville
- Richard Stalter**,
College of St. Benedict and St. John's University
- Sonja Stampfler**, *Kellogg Community College*
- Karl Sternberg**, *Western New England College*
- Pat Steubing**, *University of Nevada, Las Vegas*
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University of Wisconsin–Madison
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- Salvatore Tavormina**,
Austin Community College
- Jeffrey Taylor**,
Slippery Rock University of Pennsylvania
- Franklyn Te**, *Miami Dade College*
- Roger E. Thibault**,
Bowling Green State University
- Ken Thomas**,
Northern Essex Community College
- Megan Thomas**,
University of Nevada, Las Vegas
- Patrick Thorpe**, *Grand Valley State University*
- Ian Tizard**, *Texas A&M University*
- Terry M. Trier**, *Grand Valley State University*
- Robert Turner**, *Western Oregon University*
- Joe Vanable**, *Purdue University*
- William Velhagen**, *New York University*
- Linda H. Vick**, *North Park University*
- J. Robert Waaland**, *University of Washington*
- Alexander Wait**, *Missouri State University*
- Douglas Walker**,
Wharton County Junior College
- James Bruce Walsh**, *The University of Arizona*
- Fred Wasserman**, *Boston University*
- R. Douglas Watson**,
The University of Alabama at Birmingham
- Chad M. Wayne**, *University of Houston*
- Cindy Wedig**,
The University of Texas–Pan American
- Michael N. Weintraub**,
The University of Toledo
- Edward Weiss**, *Christopher Newport University*
- Mark Weiss**, *Wayne State University*
- Adrian M. Wenner**,
University of California, Santa Barbara
- Sue Simon Westendorf**, *Ohio University*
- Ward Wheeler**, *American Museum of Natural
History, Division of Invertebrate Zoology*
- Adrienne Williams**,
University of California, Irvine
- Elizabeth Willott**, *The University of Arizona*
- Mary Wise**,
Northern Virginia Community College
- Charles R. Wyttenbach**,
The University of Kansas
- Robert Yost**, *Indiana University–
Purdue University Indianapolis*
- Yunde Zhao**, *University of California, San Diego*
- Heping Zhou**, *Seton Hall University*
- Xinsheng Zhu**,
University of Wisconsin–Madison
- Adrienne Zihlman**,
University of California, Santa Cruz

Unanswered Questions Contributors

Chapter 2

Li Li, *Pennsylvania State University, University Park*

Chapter 3

Michael S. Brown and Joseph L. Goldstein,
University of Texas Southwestern Medical School

Chapter 4

Ulrich Müller, *University of California, San Diego*

Chapter 5

Matthew Welch, *University of California, Berkeley*

Chapter 6

Peter Agre, *Johns Hopkins Malaria Research Institute*

Chapter 7

Jeffrey Blaustein, *University of Massachusetts Amherst*

Chapter 8

Gail A. Breen, *University of Texas at Dallas*

Chapter 9

David Kramer, *Washington State University*

Chapter 10

Raymond Deshaies, *California Institute of Technology*

Chapter 11

Monica Colaiácovo, *Harvard Medical School*

Chapter 12

Nicholas Katsanis, *Duke University*

Chapter 13

Michelle Le Beau and Angela Stoddart,
The University of Chicago

Chapter 14

Janis Champay, *Reed College*

Chapter 15

Harry Noller, *University of California, Santa Cruz*

Chapter 16

Mark A. Kay, *Stanford University School of Medicine*

Chapter 17

Gerald Baron, *Rocky Mountain Laboratories*

Chapter 18

John F. Engelhardt and Tom Lynch, *University of Iowa*

Chapter 19

Larisa H. Cavallari,
University of Illinois at Chicago College of Pharmacy

Chapter 20

Douglas J. Futuyma, *Stony Brook University*

Chapter 21

Mohamed Noor, *Duke University*

Chapter 22

Jerry Coyne, *University of Chicago*

Chapter 23

Elena M. Kramer, *Harvard University*

Chapter 24

Richard Glor, *University of Rochester*

Chapter 25

Andrew Pohorille,
National Aeronautics and Space Administration (NASA)

Chapter 26

Stephen D. Bell and Rachel Y. Samson, *Oxford University*

Chapter 27

Geoff McFadden, *University of Melbourne*

Chapter 28
Michael S. Barker, *University of Arizona*

Chapter 29
Amy Litt, *The New York Botanical Garden*

Chapter 30
Todd Osmundson, *University of California, Berkeley*

Chapter 31
William S. Irby, *Georgia Southern University*

Chapter 32
Marvalee H. Wake, *University of California, Berkeley*

Chapter 33
Jennifer Fletcher, *University of California, Berkeley*

Chapter 34
Diane M. Beckles, *University of California, Davis*

Chapter 35
Michael Weintraub, *University of Toledo*

Chapter 36
Ravi Palanivelu, *University of Arizona*

Chapter 37
Christopher A. Cullis, *Case Western Reserve University*

Chapter 38
R. Daniel Rudic, *Medical College of Georgia*

Chapter 39
Paul S. Katz, *Georgia State University*

Chapter 40
Josh Dubnau, *Cold Spring Harbor Laboratory*

Chapter 41
Rona Delay, *University of Vermont*

Chapter 42
Leena Hilakivi-Clarke, *Georgetown University*

Chapter 43
Buel (Dan) Rodgers, *Washington State University*

Chapter 44
Russell Doolittle, *University of California at San Diego*

Chapter 45
Kathleen Collins, *University of Michigan at Ann Arbor*

Chapter 46
Ralph Fregosi, *University of Arizona*

Chapter 47
Mark Sheridan, *North Dakota State University*

Chapter 48
Martin Pollak, *Harvard Medical School*

Chapter 49
David Miller, *University of Illinois at Urbana-Champaign*

Chapter 50
Laura Carruth, *Georgia State University*

Chapter 51
Camille Parmesan, *The University of Texas at Austin*

Chapter 52
David Reznick, *University of California, Riverside*

Chapter 53
Anurag Agrawal, *Cornell University*

Chapter 54
Kevin Griffin, *Lamont-Doherty Earth Observatory of
Columbia University*

Chapter 55
Eric Dinerstein, *World Wildlife Fund*

Chapter 56
Michael J. Ryan, *The University of Texas at Austin*

Contents

1 Introduction to Biological Concepts and Research 1

- 1.1 What Is Life? Characteristics of Living Organisms 2
- 1.2 Biological Evolution 6
- 1.3 Biodiversity and the Tree of Life 9
- 1.4 Biological Research 13
 - Review Key Concepts 19
 - Understand & Apply 20
 - Figure 1.14 Research Method** The Scientific Method 14
 - Figure 1.15 Experimental Research** Hypothetical Experiment Illustrating the Use of Control Treatment and Replicates 16
 - Figure 1.16 Observational Research** A Field Study Using a Null Hypothesis 17

Unit One Molecules and Cells

2 Life, Chemistry, and Water 22

- 2.1 The Organization of Matter: Elements and Atoms 23
- 2.2 Atomic Structure 24
- 2.3 Chemical Bonds and Chemical Reactions 28
- 2.4 Hydrogen Bonds and the Properties of Water 32
- 2.5 Water Ionization and Acids, Bases, and Buffers 36
 - Review Key Concepts 39
 - Understand & Apply 40
 - Focus on Applied Research** Using Radioisotopes to Save Lives 26

3 Biological Molecules: The Carbon Compounds of Life 42

- 3.1 Formation and Modification of Biological Molecules 43
- 3.2 Carbohydrates 47
- 3.3 Lipids 50
- 3.4 Proteins 55
- 3.5 Nucleotides and Nucleic Acids 63
 - Review Key Concepts 68
 - Understand & Apply 69
 - Focus on Applied Research** Fats, Cholesterol, and Coronary Artery Disease 52
 - Figure 3.24 Experimental Research** Anfinsen's Experiment Demonstrating That the Amino Acid Sequence of a Protein Specifies Its Tertiary Structure 61
 - Insights from the Molecular Revolution** A Big Bang in Protein Structure Evolution: How did the domain organization in proteins evolve? 62

4 Energy, Enzymes, and Biological Reactions 71

- 4.1 Energy, Life, and the Laws of Thermodynamics 72
- 4.2 Free Energy and Spontaneous Reactions 74
- 4.3 Adenosine Triphosphate (ATP): The Energy Currency of the Cell 76
- 4.4 Role of Enzymes in Biological Reactions 78
- 4.5 Conditions and Factors That Affect Enzyme Activity 81
- 4.6 RNA-Based Biological Catalysts: Ribozymes 85
 - Review Key Concepts 87
 - Understand & Apply 88
 - Insights from the Molecular Revolution** Ribozymes: Can RNA catalyze peptide bond formation in protein synthesis? 85

5 The Cell: An Overview 90

- 5.1 Basic Features of Cell Structure and Function 91
- 5.2 Prokaryotic Cells 95
- 5.3 Eukaryotic Cells 97
- 5.4 Specialized Structures of Plant Cells 111
- 5.5 The Animal Cell Surface 113
 - Review Key Concepts 116
 - Understand & Apply 117
 - Figure 5.4 Research Method** Light and Electron Microscopy 93
 - Insights from the Molecular Revolution** An Old Kingdom in a New Domain: Do archaeans define a distinct domain of life? 96
 - Figure 5.8 Research Method** Cell Fractionation 97
 - Figure 5.11 Experimental Research** Discovery of the Nuclear Localization Signal 101

6 Membranes and Transport 119

- 6.1 Membrane Structure and Function 120
- 6.2 Functions of Membranes in Transport: Passive Transport 126
- 6.3 Passive Water Transport and Osmosis 129
- 6.4 Active Transport 131
- 6.5 Exocytosis and Endocytosis 134
 - Review Key Concepts 138
 - Understand & Apply 139
 - Focus on Applied Research** Keeping Membranes Fluid at Cold Temperatures 123
 - Figure 6.6 Experimental Research** The Frye–Edidin Experiment Demonstrating That the Phospholipid Bilayer Is Fluid 124
 - Figure 6.7 Research Method** Freeze Fracture 125
 - Insights from the Molecular Revolution** Research Serendipity: The discovery of receptor-mediated endocytosis 136

- 7 Cell Communication** 141
- 7.1** Cell Communication: An Overview 142
- 7.2** Cell Communication Systems with Surface Receptors 145
- 7.3** Surface Receptors with Built-in Protein Kinase Activity: Receptor Tyrosine Kinases 147
- 7.4** G-Protein–Coupled Receptors 149
- 7.5** Pathways Triggered by Internal Receptors: Steroid Hormone Receptors 154
- 7.6** Integration of Cell Communication Pathways 156
- Review Key Concepts 158
- Understand & Apply 159
- Figure 7.2 Experimental Research** Sutherland’s Experiments Discovering a Second Messenger Molecule 144
- Focus on Basic Research** Detecting Calcium Release in Cells 153
- Insights from the Molecular Revolution** Virus Infections and Cell Signaling Pathways: Does influenza virus propagation involve a cellular MAP kinase cascade? 155

- 8 Harvesting Chemical Energy: Cellular Respiration** 161
- 8.1** Overview of Cellular Energy Metabolism 162
- 8.2** Glycolysis: Splitting the Sugar in Half 165
- 8.3** Pyruvate Oxidation and the Citric Acid Cycle 168
- 8.4** Oxidative Phosphorylation: The Electron Transfer System and Chemiosmosis 171
- 8.5** Fermentation 176
- Review Key Concepts 179
- Understand & Apply 180
- Figure 8.15 Experimental Research** The Racker and Stoeckenius Experiment Demonstrating That an H^+ Gradient Powers ATP Synthesis by ATP Synthase 174
- Insights from the Molecular Revolution** Hot Potatoes: Do plants use uncoupling proteins to generate heat? 178

- 9 Photosynthesis** 182
- 9.1** Photosynthesis: An Overview 183
- 9.2** The Light-Dependent Reactions of Photosynthesis 185
- 9.3** The Light-Independent Reactions of Photosynthesis 193
- 9.4** Photorespiration and Alternative Processes of Carbon Fixation 196
- 9.5** Photosynthesis and Cellular Respiration Compared 199
- Review Key Concepts 202
- Understand & Apply 203
- Focus on Basic Research** Two-Dimensional Paper Chromatography and the Calvin Cycle 193
- Insights from the Molecular Revolution** Small but Pushy: What is the function of the small subunit of rubisco? 196

- 10 Cell Division and Mitosis** 205
- 10.1** The Cycle of Cell Growth and Division: An Overview 206
- 10.2** The Mitotic Cell Cycle 207
- 10.3** Formation and Action of the Mitotic Spindle 212
- 10.4** Cell Cycle Regulation 214
- 10.5** Cell Division in Prokaryotes 220
- Review Key Concepts 222
- Understand & Apply 223
- Figure 10.7 Research Method** Preparing a Human Karyotype 211
- Figure 10.12 Experimental Research** Movement of Chromosomes during Anaphase of Mitosis 215
- Figure 10.14 Experimental Research** Demonstrating the Existence of Molecules Controlling the Cell Cycle by Cell Fusion 216
- Focus on Research Organisms** The Yeast *Saccharomyces cerevisiae* 218
- Insights from the Molecular Revolution** Herpesviruses and Uncontrolled Cell Division: How does herpesvirus 8 transform normal cells into cancer cells? 220

Unit Two Genetics

- 11 Meiosis: The Cellular Basis of Sexual Reproduction** 225
- 11.1** The Mechanisms of Meiosis 226
- 11.2** Mechanisms That Generate Genetic Variability 230
- 11.3** The Time and Place of Meiosis in Organismal Life Cycles 233
- Review Key Concepts 236
- Understand & Apply 237
- Insights from the Molecular Revolution** Meiosis and Mammalian Gamete Formation: What determines whether an egg or a sperm will form? 231
- 12 Mendel, Genes, and Inheritance** 239
- 12.1** The Beginnings of Genetics: Mendel’s Garden Peas 240
- 12.2** Later Modifications and Additions to Mendel’s Principles 251
- Review Key Concepts 258
- Understand & Apply 259
- Figure 12.3 Research Method** Making a Genetic Cross between Two Pea Plants 241
- Figure 12.5 Experimental Research** The Principle of Segregation: Inheritance of Flower Color in Garden Peas 244
- Figure 12.8 Experimental Research** Testing the Predicted Outcomes of Genetic Crosses 247
- Figure 12.9 Experimental Research** The Principle of Independent Assortment 248
- Insights from the Molecular Revolution** Mendel’s Dwarf Pea Plants: How does a gene defect produce dwarfing? 252
- Figure 12.13 Experimental Research** Experiment Showing Incomplete Dominance of a Trait 253

13 Genes, Chromosomes, and Human Genetics 261

- 13.1 Genetic Linkage and Recombination 262
- 13.2 Sex-Linked Genes 266
- 13.3 Chromosomal Mutations That Affect Inheritance 271
- 13.4 Human Genetics and Genetic Counseling 276
- 13.5 Non-Mendelian Patterns of Inheritance 280

Review Key Concepts 283

Understand & Apply 284

Figure 13.2 Experimental Research Evidence for Gene Linkage 263

Focus on Model Research Organisms The Marvelous Fruit Fly, *Drosophila melanogaster* 264

Figure 13.8 Experimental Research Evidence for Sex-Linked Genes 269

Insights from the Molecular Revolution Achondroplasia: What is the gene defect that is responsible for the trait? 278

14 DNA Structure, Replication, and Organization 286

- 14.1 Establishing DNA as the Hereditary Molecule 287
- 14.2 DNA Structure 290
- 14.3 DNA Replication 293
- 14.4 Mechanisms That Correct Replication Errors 303
- 14.5 DNA Organization in Eukaryotes and Prokaryotes 304

Review Key Concepts 307

Understand & Apply 308

Figure 14.2 Experimental Research Griffith's Experiment with Virulent and Nonvirulent Strains of *Streptococcus pneumoniae* 288

Figure 14.3 Experimental Research The Hershey and Chase Experiment Demonstrating That DNA Is the Hereditary Molecule 289

Figure 14.9 Experimental Research The Meselson and Stahl Experiment Demonstrating the Semiconservative Model for DNA Replication to Be Correct 294

Insights from the Molecular Revolution A Fragile Connection between DNA Replication and Mental Retardation: What is the molecular basis for fragile X syndrome? 301

15 From DNA to Protein 310

- 15.1 The Connection between DNA, RNA, and Protein 311
- 15.2 Transcription: DNA-Directed RNA Synthesis 317
- 15.3 Production of mRNAs in Eukaryotes 318
- 15.4 Translation: mRNA-Directed Polypeptide Synthesis 321
- 15.5 Genetic Changes That Affect Protein Structure and Function 331

Review Key Concepts 336

Understand & Apply 337

Figure 15.2 Experimental Research Relationship between Genes and Enzymes 312

Insights from the Molecular Revolution Peptidyl Transferase: Protein or RNA? 327

16 Regulation of Gene Expression 339

- 16.1 Regulation of Gene Expression in Prokaryotes 340
- 16.2 Regulation of Transcription in Eukaryotes 344
- 16.3 Posttranscriptional, Translational, and Posttranslational Regulation 352
- 16.4 Genetic and Molecular Regulation of Development 355
- 16.5 The Genetics of Cancer 360

Review Key Concepts 365

Understand & Apply 367

Insights from the Molecular Revolution A Viral Tax on Transcriptional Regulation: How does human T-cell leukemia virus cause cancer? 362

17 Bacterial and Viral Genetics 369

- 17.1 Gene Transfer and Genetic Recombination in Bacteria 370
- 17.2 Viruses and Viral Genetics 377
- 17.3 Viroids and Prions, Infectious Agents Lacking Protein Coats 387

Review Key Concepts 388

Understand & Apply 389

Focus on Model Research Organisms *Escherichia coli* 370

Figure 17.1 Experimental Research Genetic Recombination in Bacteria 371

Figure 17.5 Research Method Replica Plating 376

Insights from the Molecular Revolution Reversing the Central Dogma: How do RNA tumor viruses replicate their genomes? 385

18 DNA Technologies: Analyzing and Modifying Genes 391

- 18.1 DNA Cloning 392
- 18.2 Applications of DNA Technologies 400

Review Key Concepts 413

Understand & Apply 414

Figure 18.3 Research Method Cloning a Gene of Interest in a Plasmid Cloning Vector 395

Figure 18.4 Research Method Synthesis of DNA from mRNA Using Reverse Transcriptase 396

Figure 18.5 Research Method DNA Hybridization to Identify a DNA Sequence of Interest 397

Figure 18.6 Research Method The Polymerase Chain Reaction (PCR) 398

Figure 18.7 Research Method Separation of DNA Fragments by Agarose Gel Electrophoresis 400

Figure 18.9 Research Method Southern Blot Analysis 402

Figure 18.12 Research Method Introduction of Genes into Mouse Embryos Using Embryonic Germ-Line Cells 406

Figure 18.14 Experimental Research The First Cloning of a Mammal 408

Figure 18.15 Research Method Using the Ti Plasmid of *Agrobacterium tumefaciens* to Produce Transgenic Plants 409

Insights from the Molecular Revolution Rice Blight: Engineering rice for resistance to the disease 411

19 Genomes and Proteomes 416

19.1 Genomics: An Overview 417

19.2 Genome Sequence Determination and Annotation 418

19.3 Determining the Functions of the Genes in a Genome 426

19.4 Genome Evolution 431

Review Key Concepts 436

Understand & Apply 437

Figure 19.1 Research Method Whole-Genome Shotgun Sequencing 418

Figure 19.2 Research Method Dideoxy (Sanger) Method for DNA Sequencing 419

Figure 19.3 Research Method Illumina/Solexa Method for DNA Sequencing 420

Figure 19.8 Research Method DNA Microarray Analysis of Gene Expression Levels 429

Unit Three Evolutionary Biology

20 Development of Evolutionary Thought 439

20.1 Recognition of Evolutionary Change 440

20.2 Darwin's Journeys 442

20.3 Evolutionary Biology since Darwin 448

Review Key Concepts 454

Understand & Apply 455

Focus on Basic Research Charles Darwin's Life as a Scientist 447

Figure 20.12 Experimental Research How Exposure to Insecticide Fosters the Evolution of Insecticide Resistance 449

Insights from the Molecular Revolution Asian Elephant or African Elephant: Which is the woolly mammoth's closest living relative? 452

21 Microevolution: Genetic Changes within Populations 456

21.1 Variation in Natural Populations 457

21.2 Population Genetics 460

21.3 The Agents of Microevolution 462

21.4 Maintaining Genetic and Phenotypic Variation 471

21.5 Adaptation and Evolutionary Constraints 475

Review Key Concepts 477

Understand & Apply 477

Figure 21.6 Experimental Research Using Artificial Selection to Demonstrate That Activity Level in Mice Has a Genetic Basis 459

Focus on Basic Research Using the Hardy–Weinberg Principle 462

Insights from the Molecular Revolution Back from the Brink: Did humpback whales lose genetic variability when they squeezed through a population bottleneck? 466

Figure 21.10 Observational Research Do Humans Experience Stabilizing Selection? 468

Figure 21.11 Observational Research How Opposing Forces of Directional Selection Produce Stabilizing Selection 469

Figure 21.13 Experimental Research Sexual Selection in Action 471

Figure 21.15 Observational Research Habitat Variation in Color and Striping Patterns of European Garden Snails 473

Figure 21.16 Experimental Research Demonstration of Frequency-Dependent Selection 474

22 Speciation 480

22.1 What Is a Species? 481

22.2 Maintaining Reproductive Isolation 484

22.3 The Geography of Speciation 486

22.4 Genetic Mechanisms of Speciation 491

Review Key Concepts 497

Understand & Apply 497

Focus on Basic Research Speciation in Hawaiian Fruit Flies 488

Figure 22.13 Observational Research Evidence for Reproductive Isolation in Bent Grass 490

Insights from the Molecular Revolution Monkey-Flower Speciation: How many genes contribute to reproductive isolation? 492

Figure 22.18 Observational Research Chromosomal Similarities and Differences among the Great Apes 495

23 Paleobiology and Macroevolution 499

23.1 The Fossil Record 500

23.2 Earth History 506

23.3 Historical Biogeography and Convergent Biotas 509

- 23.4** The History of Biodiversity 512
- 23.5** Interpreting Evolutionary Lineages 515
- 23.6** The Evolution of Morphological Novelties 518
- Review Key Concepts 525
- Understand & Apply 526
- Figure 23.4 Research Method** Radiometric Dating 504
- Figure 23.19 Observational Research** Evidence of Phyletic Gradualism 517
- Figure 23.20 Observational Research** Evidence of a Punctuated Pattern of Morphological Change 518
- Figure 23.23 Observational Research** Paedomorphosis in *Delphinium* Flowers 520
- Insights from the Molecular Revolution** Fancy Footwork from Fins to Fingers 523

24 Systematics and Phylogenetics: Revealing the Tree of Life 528

- 24.1** Nomenclature and Classification 529
- 24.2** Phylogenetic Trees 530
- 24.3** Sources of Data for Phylogenetic Analyses 533
- 24.4** Traditional Classification and Paraphyletic Groups 536
- 24.5** The Cladistic Revolution 538
- 24.6** Phylogenetic Trees as Research Tools 544
- 24.7** Molecular Phylogenetic Analyses 547
- Review Key Concepts 550
- Understand & Apply 551
- Insights from the Molecular Revolution** Evolution of Whales: SINEs yield signs of the LINEs of evolution 537
- Figure 24.11 Research Method** Using Cladistics to Construct a Phylogenetic Tree 540
- Figure 24.13 Research Method** Using Genetic Distances to Construct a Phylogenetic Tree 544
- Figure 24.14 Observational Research** Do Molecular Clocks Tick at a Constant Rate? 545

Unit Four Biodiversity

25 The Origin of Life 553

- 25.1** The Formation of Molecules Necessary for Life 554
- 25.2** The Origin of Cells 557
- 25.3** The Origins of Eukaryotic Cells 561
- Review Key Concepts 564
- Understand & Apply 565
- Figure 25.2 Experimental Research** The Miller–Urey Apparatus Demonstrating That Organic Molecules Can Be Synthesized Spontaneously under Conditions Simulating Primordial Earth 556
- Insights from the Molecular Revolution** Toward the Evolution of Life in the Lab: The construction of protocell-like vesicles containing an active ribozyme 559

26 Prokaryotes: Bacteria and Archaea 567

- 26.1** Prokaryotic Structure and Function 568
- 26.2** The Domain Bacteria 577
- 26.3** The Domain Archaea 582
- Review Key Concepts 585
- Understand & Apply 586
- Insights from the Molecular Revolution** Gums the Word: Gene expression changes in an oral cavity pathogen associated with transition from free-living to biofilm 576
- Figure 26.13 Experimental Research** Demonstration of the Bacterial Cause of Peptic Ulcers 579

27 Protists 587

- 27.1** What Is a Protist? 588
- 27.2** The Protist Groups 591
- Review Key Concepts 608
- Understand & Apply 609
- Focus on Applied Research** Malaria and the *Plasmodium* Life Cycle 595
- Figure 27.11 Experimental Research** The Evolutionary History of Diatoms as Revealed by Genome Analysis 597
- Insights from the Molecular Revolution** Getting the Slime Mold Act Together: What molecules regulate development of *Dictyostelium*? 605

28 Seedless Plants 611

- 28.1** The Transition to Life on Land 612
- 28.2** Bryophytes: Nonvascular Land Plants 618
- 28.3** Seedless Vascular Plants 621
- Review Key Concepts 627
- Understand & Apply 627
- Insights from the Molecular Revolution** The Powerful Genetic Toolkit for Studying Plant Evolution 626

29 Seed Plants 630

- 29.1** Gymnosperms: The “Naked Seed” Plants 631
- 29.2** Angiosperms: Flowering Plants 637
- 29.3** Frontiers of Plant Genome Research 643
- Review Key Concepts 645
- Understand & Apply 646
- Figure 29.14 Experimental Research** Analyzing Phytochromes to Explore Angiosperm Evolution 640
- Insights from the Molecular Revolution** Jump Starting Studies on Plant Genome Evolution 644

- 30 Fungi** 649
- 30.1** General Characteristics of Fungi 650
- 30.2** Major Groups of Fungi 654
- 30.3** Fungal Associations 663
- Review Key Concepts 667
- Understand & Apply 668
- Insights from the Molecular Revolution** There Was Probably a Fungus among Us 656
- Focus on Applied Research** Lichens as Monitors of Air Pollution's Biological Damage 664

31 Animal Phylogeny, Acoelomates, and Protostomes 670

- 31.1** What Is an Animal? 671
- 31.2** Key Innovations in Animal Evolution 672
- 31.3** An Overview of Animal Phylogeny and Classification 675
- 31.4** Animals without Tissues: Parazoa 677
- 31.5** Eumetazoans with Radial Symmetry 679
- 31.6** Lophotrochozoan Protostomes 683
- 31.7** Ecdysozoan Protostomes 693
- Review Key Concepts 703
- Understand & Apply 704
- Focus on Applied Research** Breaking the Life Cycles of Parasitic Worms 686
- Focus on Model Research** Organisms *Caenorhabditis elegans* 694
- Insights from the Molecular Revolution** Unscrambling the Arthropods: Morphological versus molecular characteristics? 696

32 Deuterostomes: Vertebrates and Their Closest Relatives 706

- 32.1** Invertebrate Deuterostomes 707
- 32.2** Overview of the Phylum Chordata 710
- 32.3** The Origin and Diversification of Vertebrates 712
- 32.4** "Agnathans": Hagfishes and Lampreys, Conodonts and Ostracoderms 715
- 32.5** Gnathostomata: The Evolution of Jaws 717
- 32.6** Tetrapoda: The Evolution of Limbs 721
- 32.7** Amniota: The Evolution of Fully Terrestrial Vertebrates 723
- 32.8** Testudines: Turtles 726
- 32.9** Living Lepidosaurs: Sphenodontids and Squamates 727
- 32.10** Living Archosaurs: Crocodylians and Birds 728
- 32.11** Mammalia: Monotremes, Marsupials, and Placentals 732
- 32.12** Nonhuman Primates 734
- 32.13** The Evolution of Humans 739

- Review Key Concepts 744
- Understand & Apply 746
- Focus on Model Research** Organisms *Anolis* Lizards of the Caribbean 729
- Insights from the Molecular Revolution** Building a Better Nose: How did the sense of smell evolve in mammals? 735

Unit Five Plant Structure and Function

33 The Plant Body 748

- 33.1** Plant Structure and Growth: An Overview 749
- 33.2** The Three Plant Tissue Systems 752
- 33.3** Primary Shoot Systems 757
- 33.4** Root Systems 764
- 33.5** Secondary Growth 767
- Review Key Concepts 771
- Understand & Apply 772
- Insights from the Molecular Revolution** Shaping Up Flower Color 758
- Focus on Basic Research** Homeobox Genes: How the Meristem Gives Its Marching Orders 761

34 Transport in Plants 774

- 34.1** Principles of Water and Solute Movement in Plants 775
- 34.2** Transport in Roots 779
- 34.3** Transport of Water and Minerals in the Xylem 781
- 34.4** Transport of Organic Substances in the Phloem 786
- Review Key Concepts 790
- Understand & Apply 791
- Insights from the Molecular Revolution** TIPs and PIPs—the Osmosis Express 779
- Figure 34.12 Experimental Research** Translocation Pressure 787

35 Plant Nutrition 793

- 35.1** Plant Nutritional Requirements 794
- 35.2** Soil 798
- 35.3** Root Adaptations for Obtaining and Absorbing Nutrients 802
- Review Key Concepts 808
- Understand & Apply 809
- Figure 35.2 Research Method** Hydroponic Culture 795
- Focus on Applied Research** Plants Poised for Environmental Cleanup 801
- Insights from the Molecular Revolution** Getting to the Roots of Plant Nutrition 803

36 Reproduction and Development in Flowering Plants 811

- 36.1 Overview of Flowering Plant Reproduction 812
- 36.2 The Formation of Flowers and Gametes 813
- 36.3 Pollination, Fertilization, and Germination 816
- 36.4 Asexual Reproduction of Flowering Plants 824
- 36.5 Early Development of Plant Form and Function 826

Review Key Concepts 835

Understand & Apply 836

Figure 36.18 Research Method Plant Cell Culture 825

Focus on Basic Research Model Research Organisms: *Arabidopsis thaliana* 827

Insights from the Molecular Revolution Trichomes: Window on development in a single plant cell 829

Figure 36.24 Experimental Research Probing the Roles of Floral Organ Identity Genes 832

37 Plant Signals and Responses to the Environment 838

- 37.1 Introduction to Plant Hormones 839
- 37.2 Plant Chemical Defenses 849
- 37.3 Plant Movements 855
- 37.4 Plant Biological Clocks 858

Review Key Concepts 863

Understand & Apply 864

Figure 37.3 Experimental Research The Darwins' Experiments on Phototropism 841

Insights from the Molecular Revolution Stressing Out in Plants and People 850

Focus on Basic Research Using DNA Microarray Analysis to Track Down "Florigen" 862

Unit Six Animal Structure and Function

38 Introduction to Animal Organization and Physiology 867

- 38.1 Organization of the Animal Body 868
- 38.2 Animal Tissues 868
- 38.3 Coordination of Tissues in Organs and Organ Systems 875
- 38.4 Homeostasis 876

Review Key Concepts 880

Understand & Apply 881

Insights from the Molecular Revolution Culturing Human Embryonic Stem Cells 871

39 Information Flow and the Neuron 883

- 39.1 Neurons and Their Organization in Nervous Systems 884
- 39.2 Signaling by Neurons 888
- 39.3 Transmission across Chemical Synapses 894
- 39.4 Integration of Incoming Signals by Neurons 897

Review Key Concepts 900

Understand & Apply 901

Figure 39.7 Experimental Research Demonstration of Chemical Transmission of Nerve Impulses at Synapses 887

Figure 39.8 Research Method Measuring Membrane Potential 888

Insights from the Molecular Revolution Dissecting Neurotransmitter Receptor Functions 896

40 Nervous Systems 903

- 40.1 Invertebrate and Vertebrate Nervous Systems Compared 904
- 40.2 The Peripheral Nervous System 906
- 40.3 The Central Nervous System and Its Functions 907
- 40.4 Memory, Learning, and Consciousness 914

Review Key Concepts 919

Understand & Apply 920

Figure 40.13 Experimental Research Investigating the Functions of the Cerebral Hemispheres 915

Insights from the Molecular Revolution Knockout Mice with a Bad Memory 917

41 Sensory Systems 921

- 41.1 Overview of Sensory Receptors and Pathways 922
- 41.2 Mechanoreceptors and the Tactile and Spatial Senses 923
- 41.3 Mechanoreceptors and Hearing 927
- 41.4 Photoreceptors and Vision 929
- 41.5 Chemoreceptors 934
- 41.6 Thermoreceptors and Nociceptors 936
- 41.7 Magnetoreceptors and Electroreceptors 937

Review Key Concepts 940

Understand & Apply 941

Insights from the Molecular Revolution Some Like It Hot: What is the nature of the capsaicin receptor? 938

42 The Endocrine System 943

- 42.1 Hormones and Their Secretion 944
- 42.2 Mechanisms of Hormone Action 946
- 42.3 The Hypothalamus and Pituitary 950
- 42.4 Other Major Endocrine Glands of Vertebrates 955
- 42.5 Endocrine Systems in Invertebrates 961

Review Key Concepts 963

Understand & Apply 964

Figure 42.5 Experimental Research Demonstration That Binding of Epinephrine to β -Adrenergic Receptors Triggers a Signal Transduction Pathway within Cells 949

Insights from the Molecular Revolution Two Receptors for Estrogens 954

Focus on Basic Research Neuroendocrine and Behavioral Effects of Anabolic-Androgenic Steroids in Humans 959

43 Muscles, Bones, and Body Movements 966

43.1 Vertebrate Skeletal Muscle: Structure and Function 967

43.2 Skeletal Systems 974

43.3 Vertebrate Movement: The Interactions between Muscles and Bones 976

Review Key Concepts 978

Understand & Apply 979

Figure 43.4 Experimental Research The Sliding Filament Model of Muscle Contraction 969

Insights from the Molecular Revolution Training Effects on Gene Expression in Racehorses 973

44 The Circulatory System 981

44.1 Animal Circulatory Systems: An Introduction 982

44.2 Blood and Its Components 985

44.3 The Heart 987

44.4 Blood Vessels of the Circulatory System 991

44.5 Maintaining Blood Flow and Pressure 994

44.6 The Lymphatic System 996

Review Key Concepts 998

Understand & Apply 1000

Insights from the Molecular Revolution Identifying the Role of a Hormone Receptor in Blood Pressure Regulation Using Knockout Mice 995

Figure 44.18 Experimental Research Demonstration of a Vasodilatory Signal Molecule 996

45 Defenses against Disease 1002

45.1 Three Lines of Defense against Pathogens 1003

45.2 Innate Immunity: Nonspecific Defenses 1004

45.3 Adaptive Immunity: Specific Defenses 1007

45.4 Malfunctions and Failures of the Immune System 1017

45.5 Defenses in Other Animals 1020

Review Key Concepts 1021

Understand & Apply 1022

Focus on Model Research Organisms The Mighty Mouse 1008

Figure 45.9 Research Method Production of Monoclonal Antibodies 1016

Insights from the Molecular Revolution Some Cancer Cells Kill Cytotoxic T Cells to Defeat the Immune System 1018

46 Gas Exchange: The Respiratory System 1024

46.1 The Function of Gas Exchange 1025

46.2 Adaptations for Respiration 1027

46.3 The Mammalian Respiratory System 1030

46.4 Mechanisms of Gas Exchange and Transport 1034

46.5 Respiration at High Altitudes and in Ocean Depths 1037

Review Key Concepts 1040

Understand & Apply 1041

Insights from the Molecular Revolution Giving Hemoglobin and Myoglobin Air 1037

Figure 46.14 Experimental Research Demonstration of a Molecular Basis for High-Altitude Adaptation in Deer Mice 1038

47 Animal Nutrition 1043

47.1 Feeding and Nutrition 1044

47.2 Digestive Processes 1046

47.3 Digestion in Humans and Other Mammals 1048

47.4 Regulation of the Digestive Process 1059

47.5 Digestive Specializations in Vertebrates 1061

Review Key Concepts 1066

Understand & Apply 1067

Insights from the Molecular Revolution Food for Thought on the Feeding Response 1062

Figure 47.21 Experimental Research Association of Intestinal Bacteria Populations with Obesity in Humans 1064

48 Regulating the Internal Environment 1069

48.1 Introduction to Osmoregulation and Excretion 1070

48.2 Osmoregulation and Excretion in Invertebrates 1072

48.3 Osmoregulation and Excretion in Mammals 1074

48.4 Regulation of Mammalian Kidney Function 1080

48.5 Kidney Function in Nonmammalian Vertebrates 1084

48.6 Introduction to Thermoregulation 1085

48.7 Ectothermy 1087

48.8 Endothermy 1088

Review Key Concepts 1093

Understand & Apply 1094

Insights from the Molecular Revolution An Ore Spells Relief for Osmotic Stress 1078

Figure 48.12 Experimental Research ADH-Stimulated Water Reabsorption in the Kidney Collecting Duct 1082

- 49 Animal Reproduction** 1096
- 49.1** Animal Reproductive Modes: Asexual and Sexual Reproduction 1097
- 49.2** Cellular Mechanisms of Sexual Reproduction 1099
- 49.3** Sexual Reproduction in Humans 1104
- 49.4** Methods for Preventing Pregnancy: Contraception 1112
- Review Key Concepts 1115
- Understand & Apply 1116
- Figure 49.13 Experimental Research** Vocal Cues of Ovulation in Human Females 1107
- Insights from the Molecular Revolution** Egging on the Sperm 1111

- 50 Animal Development** 1118
- 50.1** Mechanisms of Embryonic Development 1119
- 50.2** Major Patterns of Cleavage and Gastrulation 1122
- 50.3** From Gastrulation to Adult Body Structures: Organogenesis 1126
- 50.4** Embryonic Development of Humans and Other Mammals 1128
- 50.5** The Cellular Basis of Development 1133
- Review Key Concepts 1142
- Understand & Apply 1143
- Insights from the Molecular Revolution** Turning on Male Development 1134
- Figure 50.18 Experimental Research** Demonstrating the Selective Adhesion Properties of Cells 1137
- Figure 50.20 Experimental Research** Spemann and Mangold's Experiment Demonstrating Induction in Embryos 1139

Unit Seven Ecology and Behavior

- 51 Ecology and the Biosphere** 1145
- 51.1** The Science of Ecology 1146
- 51.2** Environmental Diversity of the Biosphere 1147
- 51.3** Organismal Responses to Environmental Variation and Climate Change 1152
- 51.4** Terrestrial Biomes 1154
- 51.5** Freshwater Environments 1161
- 51.6** Marine Environments 1164
- Review Key Concepts 1169
- Understand & Apply 1170
- Insights from the Molecular Revolution** Frozen Fish? Not if they have antifreeze proteins 1152
- Figure 51.9 Observational Research** How Do Lizards Compensate for Altitudinal Variation in Environmental Temperature? 1153
- Focus on Basic Research** Exploring the Rainforest Canopy 1157
- Figure 51.25 Experimental Research** What Causes Lake Eutrophication? 1164

- 52 Population Ecology** 1172
- 52.1** Population Characteristics 1173
- 52.2** Demography 1175
- 52.3** The Evolution of Life Histories 1178
- 52.4** Models of Population Growth 1180
- 52.5** Population Dynamics 1184
- 52.6** Human Population Growth 1191
- Review Key Concepts 1196
- Understand & Apply 1197
- Figure 52.3 Research Method** Using Mark-Release-Recapture to Estimate Population Size 1174
- Insights from the Molecular Revolution** Asocial Armadillos: Can armadillo reproductive patterns explain the expansion of their range? 1176
- Focus on Basic Research** The Evolution of Life History Traits in Guppies 1180
- Figure 52.17 Experimental Research** Evaluating Density-Dependent Interactions between Species 1188
- Figure 52.19 Observational Research** Do Immigrants from Source Populations Prevent Extinction of Sink Populations of the Bay Checkerspot Butterfly? 1190
- 53 Population Interactions and Community Ecology** 1199
- 53.1** Population Interactions 1200
- 53.2** The Nature of Ecological Communities 1208
- 53.3** Community Characteristics 1210
- 53.4** Effects of Population Interactions on Community Characteristics 1213
- 53.5** Effects of Disturbance on Community Characteristics 1216
- 53.6** Ecological Succession: Responses to Disturbance 1217
- 53.7** Variations in Species Richness among Communities 1221
- Review Key Concepts 1226
- Understand & Apply 1227
- Figure 53.8 Experimental Research** Gause's Experiments on Interspecific Competition in *Paramecium* 1204
- Figure 53.12 Experimental Research** Demonstration of Competition between Two Species of Barnacles 1206
- Figure 53.23 Experimental Research** Effect of a Predator on the Species Richness of Its Prey 1214
- Figure 53.24 Experimental Research** The Complex Effects of an Herbivorous Snail on Algal Species Richness 1215
- Insights from the Molecular Revolution** The Species-Area Effect: Does bacterial species richness vary with "island" size? 1224
- 54 Ecosystems** 1229
- 54.1** Modeling Ecosystem Processes 1230
- 54.2** Energy Flow and Ecosystem Energetics 1232
- 54.3** Nutrient Cycling in Ecosystems 1241
- 54.4** Human Disruption of Ecosystem Processes 1246

Review Key Concepts 1251

Understand & Apply 1252

Figure 54.7 Observational Research What Is the Pattern of Energy Flow within the Silver Springs Ecosystem? 1236

Focus on Applied Research Biological Magnification and the Accumulation of Toxins at Higher Trophic Levels 1239

Figure 54.11 Experimental Research A Trophic Cascade in Salt Marshes 1240

Focus on Basic Research Studies of the Hubbard Brook Watershed 1242

Insights from the Molecular Revolution Ocean Acidification: Does it affect gene expression? 1248

55 Biodiversity and Conservation Biology 1254

55.1 The Biodiversity Crisis on Land, in the Sea, and in River Systems 1255

55.2 Specific Threats to Biodiversity 1258

55.3 The Value of Biodiversity 1263

55.4 Where Biodiversity Is Most Threatened 1264

55.5 Conservation Biology: Principles and Theory 1266

55.6 Conservation Biology: Practical Strategies and Economic Tools 1271

Review Key Concepts 1275

Understand & Apply 1276

Figure 55.6 Experimental Research Predation on Songbird Nests in Forests and Forest Fragments 1259

Insights from the Molecular Revolution Developing a DNA Barcode System 1267

Focus on Applied Research Preserving the Yellow-Bellied Glider 1269

Figure 55.18 Experimental Research Effect of Landscape Corridors on Plant Species Richness in Habitat Fragments 1271

56 Animal Behavior 1278

56.1 Instinctive and Learned Behaviors 1279

56.2 Neurophysiological and Endocrine Control of Behavior 1285

56.3 Migration and Wayfinding 1288

56.4 Habitat Selection and Territoriality 1292

56.5 The Evolution of Communication 1293

56.6 The Evolution of Reproductive Behavior and Mating Systems 1296

56.7 The Evolution of Social Behavior 1299

Review Key Concepts 1304

Understand & Apply 1305

Figure 56.2 Experimental Research The Role of Sign Stimuli in Parent–Offspring Interactions 1281

Insights from the Molecular Revolution A Knockout by a Whisker: What is the function of disheveled genes in mice? 1283

Figure 56.10 Experimental Research Effects of the Social Environment on Brain Anatomy and Chemistry 1288

Figure 56.13 Experimental Research Experimental Analysis of the Indigo Bunting’s Star Compass 1290

Figure 56.27 Research Method Calculating Degrees of Relatedness 1301

Appendix A: Answers A-1

Appendix B: Classification System A-36

Glossary G-1

Index I-1



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Earth, a planet teeming with life, is seen here in a satellite photograph.

Introduction to Biological Concepts and Research

Why it matters . . . Life abounds in almost every nook and cranny on our planet Earth. A lion creeps across an African plain, ready to spring at a zebra. The leaves of a sunflower in Kansas turn slowly through the day, keeping their surfaces fully exposed to rays of sunlight. Fungi and bacteria in the soil of a Canadian forest obtain nutrients by decomposing dead organisms. A child plays in a park in Madrid, laughing happily as his dog chases a tennis ball. In one room of a nearby hospital, a mother hears the first cry of her newborn baby; in another room, an elderly man sighs away his last breath. All over the world, countless organisms are born, live, and die every moment of every day. How did life originate, how does it persist, and how is it changing? Biology, the science of life, provides scientific answers to these questions.

What *is* life? Offhandedly, you might say that although you cannot define it, you know it when you see it. The question has no simple answer, because life has been unfolding for billions of years, ever since nonliving materials assembled into the first organized, living cells. Clearly, any list of criteria for the living state only hints at the meaning of “life.” Deeper scientific insight requires a wide-ranging examination of the characteristics of life, which is what this book is all about.

Over the next semester or two, you will encounter examples of how organisms are constructed, how they function, where they live, and what they do. The examples provide evidence in support of concepts that will greatly enhance your appreciation and understanding of the living world, including its fundamental unity and striking diversity. This chapter provides a brief overview of these basic concepts. It also describes some of the ways in which biologists conduct research, the process by which they observe nature, formulate explanations of their observations, and test their ideas.

STUDY OUTLINE

- 1.1 What Is Life?
Characteristics of Living Organisms
- 1.2 Biological Evolution
- 1.3 Biodiversity and the Tree of Life
- 1.4 Biological Research

FIGURE 1.1 Living organisms and inanimate objects. Living organisms, such as this lizard (*Iguana iguana*), have characteristics that are fundamentally different from those of inanimate objects, like the rock on which it is sitting.



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1.1 What Is Life? Characteristics of Living Organisms

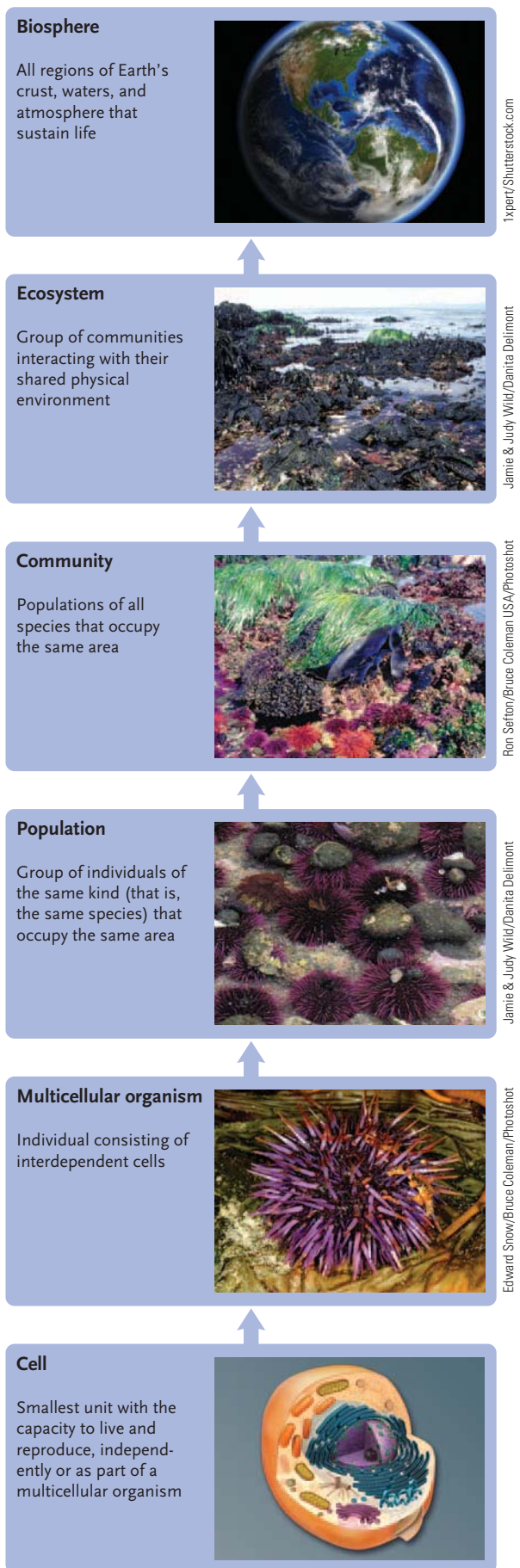
Picture a lizard on a rock, slowly turning its head to follow the movements of another lizard nearby (**Figure 1.1**). You know that the lizard is alive and that the rock is not. At the atomic and molecular levels, however, the differences between them blur. Lizards, rocks, and all other matter are composed of atoms and molecules, which behave according to the same physical laws. Nevertheless, living organisms share a set of characteristics that collectively set them apart from nonliving matter.

The differences between a lizard and a rock depend not only on the kinds of atoms and molecules present, but also on their organization and their interactions. Individual organisms are at the middle of a hierarchy that ranges from the atoms and molecules within their bodies to the assemblages of organisms that occupy Earth's environments. Within every individual, certain biological molecules contain instructions for building other molecules, which, in turn, are assembled into complex structures. Living organisms must gather energy and materials from their surroundings to build new biological molecules, grow in size, maintain and repair their parts, and produce offspring. They must also respond to environmental changes by altering their chemistry and activity in ways that allow them to survive. Finally, the structure and function of living organisms often change from one generation to the next.

Life on Earth Exists at Several Levels of Organization, Each with Its Own Emergent Properties

The organization of life extends through several levels of a hierarchy (**Figure 1.2**). Complex biological molecules exist at the lowest level of organization, but by themselves, these molecules are not alive. The properties of life do not appear until they are arranged into cells. A **cell** is an organized chemical system that includes many spe-

FIGURE 1.2 The hierarchy of life. Each level in the hierarchy of life exhibits emergent properties that do not exist at lower levels. The middle four photos depict a rocky intertidal zone on the coast of Washington State.
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cialized molecules surrounded by a membrane. A cell is the lowest level of biological organization that can survive and reproduce—as long as it has access to a usable energy source, the necessary raw materials, and appropriate environmental conditions. However, a cell is alive only as long as it is organized as a cell; if broken into its component parts, a cell is no longer alive even if the parts themselves are unchanged. Characteristics that depend on the level of organization of matter, but do not exist at lower levels of organization, are called **emergent properties**. Life is thus an emergent property of the organization of matter into cells.

Many single cells, such as bacteria and protozoans, exist as **unicellular organisms**. By contrast, plants and animals are **multicellular organisms**. Their cells live in tightly coordinated groups and are so interdependent that they cannot survive on their own. For example, human cells cannot live by themselves in nature because they must be bathed in body fluids and supported by the activities of other cells. Like individual cells, multicellular organisms have emergent properties that their individual components lack; for example, humans can learn biology.

The next, more inclusive level of organization is the **population**, a group of organisms of the same kind that live together in the same place. The humans who occupy the island of Tahiti and a group of sea urchins living together on the coast of Washington State are examples of populations. Like multicellular organisms, populations have emergent properties that do not exist at lower levels of organization. For example, a population has characteristics such as its birth or death rate—that is, the number of individual organisms who are born or die over a period of time—that do not exist for single cells or individual organisms.

Working our way up the biological hierarchy, all the populations of different organisms that live in the same place form a **community**. The algae, snails, sea urchins, and other

organisms that live along the coast of Washington State, taken together, make up a community. The next higher level, the **ecosystem**, includes the community *and* the nonliving environmental factors with which it interacts. For example, a coastal ecosystem comprises a community of living organisms, as well as rocks, air, seawater, minerals, and sunlight. The highest level, the **biosphere**, encompasses all the ecosystems of Earth's waters, crust, and atmosphere. Communities, ecosystems, and the biosphere also have emergent properties. For example, communities can be described in terms of their *diversity*—the number and types of different populations they contain—and their *stability*—the degree to which the populations within the community remain the same through time.

Living Organisms Contain Chemical Instructions That Govern Their Structure and Function

The most fundamental and important molecule that distinguishes living organisms from nonliving matter is **deoxyribonucleic acid (DNA; Figure 1.3)**. DNA is a large, double-stranded, helical molecule that contains instructions for assembling a living organism from simpler molecules. We recognize bacteria, trees, fishes, and humans as different because differences in their DNA produce differences in their appearance and function. (Some nonliving systems, notably certain viruses, also contain DNA, but biologists do not consider viruses to be alive because they cannot reproduce independently of the organisms they infect.)

DNA functions similarly in all living organisms. As you will discover in Chapters 14 and 15, the instructions in DNA are copied into molecules of a related substance, **ribonucleic acid (RNA)**, which then directs the synthesis (production) of different protein molecules (**Figure 1.4**). **Proteins** carry out most of the activities of life, including the synthesis of all other biological

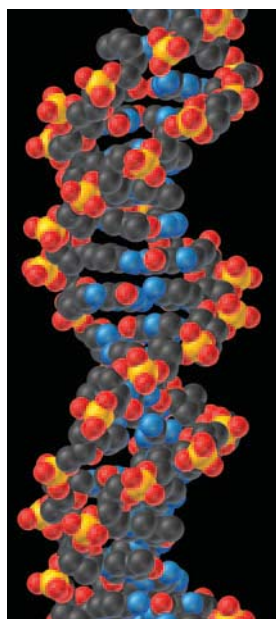


FIGURE 1.3 Deoxyribonucleic acid (DNA). A computer-generated model of DNA illustrates that it is made up of two strands twisted into a double helix.

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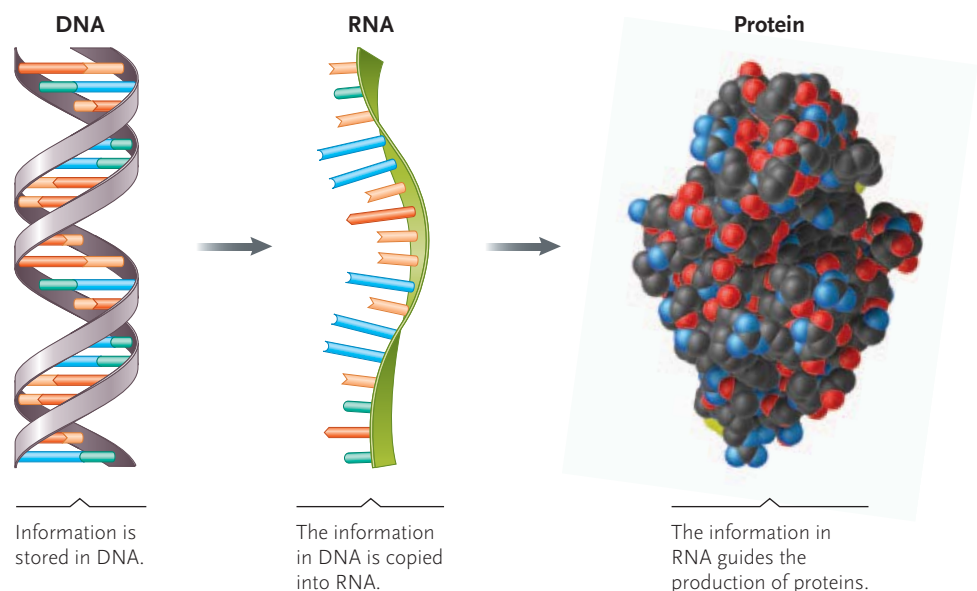


FIGURE 1.4 The pathway of information flow in living organisms. Information stored in DNA is copied into RNA, which then directs the construction of protein molecules. The protein shown here is lysozyme.

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molecules. This pathway is preserved from generation to generation by the ability of DNA to copy itself so that offspring receive the same basic molecular instructions as their parents.

Living Organisms Engage in Metabolic Activities

Metabolism, described in Chapters 8 and 9, is another key property of living cells and organisms. **Metabolism** describes the ability of a cell or organism to extract energy from its surroundings and use that energy to maintain itself, grow, and reproduce. As a part of metabolism, cells carry out chemical reactions that assemble, alter, and disassemble molecules (**Figure 1.5**). For example, a growing sunflower plant carries out **photosynthesis**, in which the electromagnetic energy in sunlight is absorbed and converted into chemical energy. The cells of the plant store some chemical energy in sugar and starch molecules, and they use the rest to manufacture other biological molecules from simple raw materials obtained from the environment.

Sunflowers concentrate some of their energy reserves in seeds from which more sunflower plants may grow. The chemical energy stored in the seeds also supports other organisms, such as insects, birds, and humans, that eat them. Most organisms, including sunflower plants, tap stored chemical energy through another metabolic process, **cellular respiration**. In cellular respiration complex biological molecules are broken down with oxygen, releasing some of their energy content for cellular activities.

Energy Flows and Matter Cycles through Living Organisms

With few exceptions, energy from sunlight supports life on Earth. Plants and other photosynthetic organisms absorb energy from sunlight and convert it into chemical energy. They use this chemical energy to assemble complex molecules, such as sugars, from simple raw materials, such as water and carbon dioxide. As such, photosynthetic organisms are the **primary producers** of the food on which all other organisms rely (**Figure 1.6**). By contrast, animals are **consumers**: directly or indirectly, they feed on the complex molecules manufactured by plants. For example, zebras tap directly into the molecules of plants when they eat grass, and lions tap into it indirectly when they eat zebras. Certain bacteria and fungi are **decomposers**: they feed on the remains of dead organisms, breaking down complex biological molecules into simpler raw materials, which may then be recycled by the producers.

As you will see in Chapter 54, much of the energy that photosynthetic organisms trap from sunlight *flows* within and between populations, communities, and ecosystems. But because the transfer of energy from one organism to another is not 100% efficient, a portion of that energy is lost as heat. Although some animals can use this form of energy to maintain body tempera-

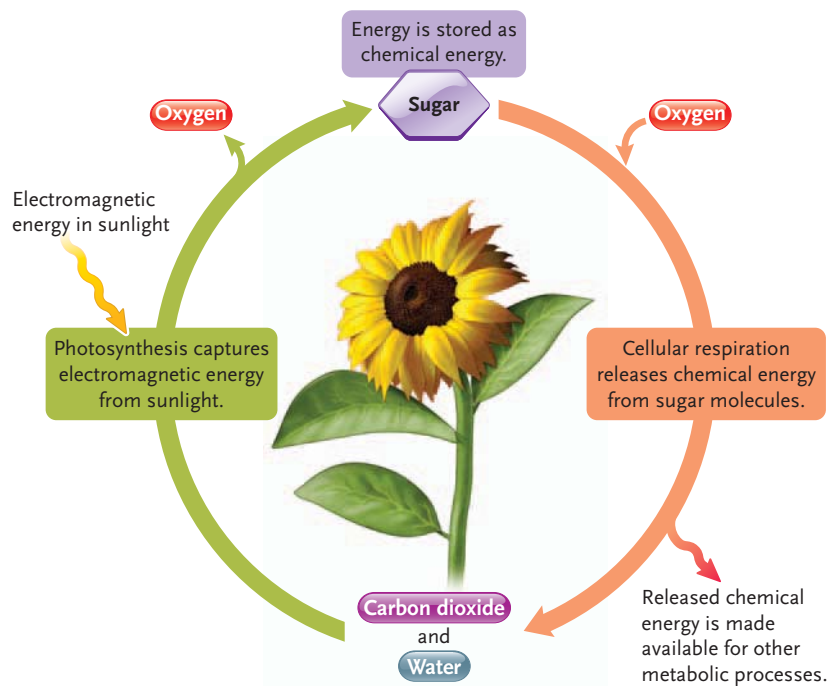


FIGURE 1.5 Metabolic activities. Photosynthesis converts the electromagnetic energy in sunlight into chemical energy, which is stored in sugars and starches built from carbon dioxide and water; oxygen is released as a by-product of the reaction. Cellular respiration uses oxygen to break down sugar molecules, releasing their chemical energy and making it available for other metabolic processes.

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ture, it cannot sustain other life processes. By contrast, matter—nutrients such as carbon and nitrogen—*cycles* between living organisms and the nonliving components of the biosphere, to be used again and again (see Figure 1.6).

Living Organisms Compensate for Changes in the External Environment

All objects, whether living or nonliving, respond to changes in the environment; for example, a rock warms up on a sunny day and cools at night. But only living organisms have the capacity to detect environmental changes and *compensate* for them through controlled responses. Diverse and varied *receptors*—molecules or larger structures located on individual cells and body surfaces—can detect changes in external and internal conditions. When stimulated, the receptors trigger reactions that produce a compensating response.

For example, your internal body temperature remains reasonably constant, even though the environment in which you live is usually either cooler or warmer than you are. Your body compensates for these environmental variations and maintains its internal temperature at about 37° Celsius (C). When the environmental temperature drops significantly, receptors in your skin detect the change and transmit that information to your brain. Your brain may send a signal to your muscles, causing you to shiver, thereby releasing heat that keeps your body temperature from dropping below its optimal level. When the environmental temperature rises significantly, glands in your skin se-

crete sweat, which evaporates, cooling the skin and its underlying blood supply. The cooled blood circulates internally and keeps your body temperature from rising above 37°C. People also compensate behaviorally by dressing warmly on a cold winter day or jumping into a swimming pool in the heat of summer. Keeping your internal temperature within a narrow range is one example of **homeostasis**—a steady internal condition maintained by responses that compensate for changes in the external environment. As described in Units 5 and 6, all organisms have mechanisms that maintain homeostasis in relation to temperature, blood chemistry, and other important factors.

Living Organisms Reproduce and Many Undergo Development

Humans and all other organisms are part of an unbroken chain of life that began at least 3.5 billion years ago. This chain continues today through **reproduction**, the process by which parents produce offspring. Offspring generally resemble their parents because the parents pass copies of their DNA—with all the accompanying instructions for virtually every life process—to their offspring. The transmission of DNA (that is, genetic information) from one generation to the next is called **inheritance**. For example, the eggs produced by storks hatch into little storks, not into pelicans, because they inherited stork DNA, which is different from pelican DNA.

Multicellular organisms also undergo a process of **development**, a series of programmed changes encoded in DNA, through which a fertilized egg divides into many cells that ultimately are transformed into an adult, which is itself capable of reproduction. As an example, consider the development of a moth (**Figure 1.7**). This insect begins its life as a tiny egg that contains all the instructions necessary for its development into an adult moth. Following these instructions, the egg first hatches into a caterpillar, a larval form adapted for feeding and rapid growth. The caterpillar increases in size until internal chemical signals indicate that it is time to spin a cocoon and become a pupa. Inside its cocoon, the pupa undergoes profound developmental changes that remodel its body completely. Some cells die; others multiply and become organized in different patterns. When these transformations are complete, the adult moth emerges from the cocoon. It is equipped with structures and behaviors, quite different from those of the caterpillar, that enable it to reproduce.

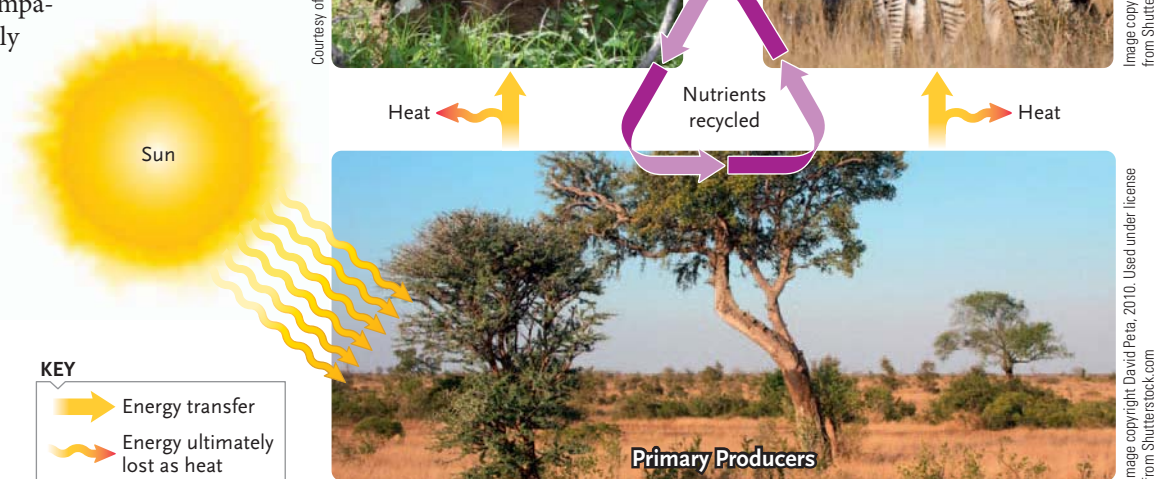


FIGURE 1.6 Energy flow and nutrient recycling. In most ecosystems, energy flows from the sun to producers to consumers to decomposers. On the African savanna, the sun provides energy to grasses (producers); zebras (primary consumers) then feed on the grasses before being eaten by lions (secondary consumers); fungi (decomposers) absorb nutrients and energy from the digestive wastes of animals and from the remains of dead animals and plants. All of the energy that enters an ecosystem is ultimately lost from the system as heat. Nutrients move through the same pathways, but they are conserved and recycled.

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The sequential stages through which individuals develop, grow, maintain themselves, and reproduce are known collectively as the **life cycle** of an organism. The moth's life cycle includes egg, larva, pupa, and adult stages. Through reproduction, adult moths continue the cycle by producing the sperm and eggs that unite to form the fertilized egg, which starts the next generation.

Populations of Living Organisms Change from One Generation to the Next

Although offspring generally resemble their parents, individuals with unusual characteristics sometimes suddenly appear in a population. Moreover, the features that distinguish these oddballs are

FIGURE 1.7 Life cycle of an atlas moth (*Attacus atlas*).

often inherited by their offspring. Our awareness of the inheritance of unusual characteristics has had an enormous impact on human history because it has allowed plant and animal breeders to produce crops and domesticated animals with especially desirable characteristics.

Biologists have observed that similar changes also take place under natural conditions. In other words, populations of all organisms change from one generation to the next, because some individuals experience changes in their DNA and they pass those modified instructions along to their offspring. We introduce this fundamental process, **biological evolution**, in the next section. Although we explore biological evolution in great detail in Unit 3, every chapter in this book—indeed, every idea in biology—references our understanding that all biological systems are the products of evolutionary change.

STUDY BREAK 1.1

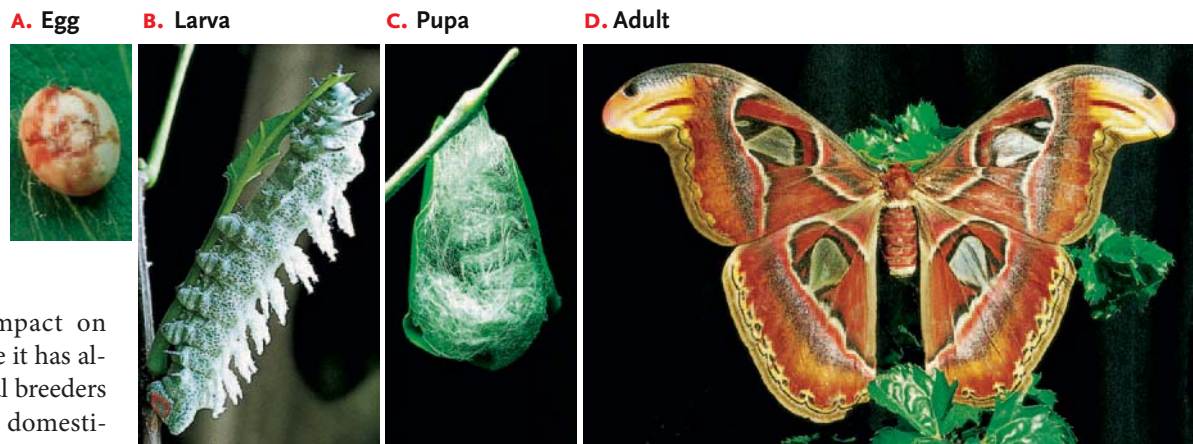
1. List the major levels in the hierarchy of life, and identify one emergent property of each level.
2. What do living organisms do with the energy they collect from the external environment?
3. What is a life cycle?

1.2 Biological Evolution

All research in biology—ranging from analyses of the precise structure of biological molecules to energy flow through the biosphere—is undertaken with the knowledge that biological evolution has shaped life on Earth. Our understanding of the evolutionary process reveals several truths about the living world: (1) all populations change through time, (2) all organisms are descended from a common ancestor that lived in the distant past, and (3) evolution has produced the spectacular diversity of life that we see around us. Evolution is the unifying theme that links all the subfields of the biological sciences, and it provides cohesion to our treatment of the many topics discussed in this book.

Darwin and Wallace Explained How Organisms Change through Time

How do evolutionary changes take place? One important mechanism was first explained in the mid-nineteenth century by two British naturalists, Charles Darwin and Alfred Russel Wallace. On



Photographs by Jack de Coringh/Animals Animals

a five-year voyage around the world, Darwin observed many “strange and wondrous” organisms. He also found fossils of species that are now extinct (that is, all members of the species are dead). The extinct forms often resembled living species in some traits but differed in others. Darwin originally believed in special creation—the idea that living organisms were placed on Earth in their present numbers and kinds and have not changed since their creation. But he became convinced that species do not remain constant with the passage of time: instead, they change from one form to another over generations. Wallace came to the same conclusion through his observations of the great variety of plants and animals in the jungles of South America and Southeast Asia.

Darwin also studied the process of evolution through observations and experiments on domesticated animals. Pigeons were among his favorite experimental subjects. Domesticated pigeons exist in a variety of sizes, colors, and shapes, but all of them are descended from the wild rock dove (**Figure 1.8**). Darwin noted that pigeon breeders who wished to promote a certain characteristic, such as elaborately curled tail feathers, selected individuals with the most curl in their feathers as parents for the next generation. By permitting only these birds to mate, the breeders fostered the desired characteristic and gradually eliminated or reduced other traits. The same practice is still used today to increase the frequency of desirable traits in tomatoes, dogs, and other domesticated plants and animals. Darwin called this practice **artificial selection**. He termed the equivalent process that occurs in nature **natural selection**.

In 1858, Darwin and Wallace formally summarized their observations and conclusions explaining biological evolution. (1) Most organisms can produce numerous offspring, but environmental factors limit the number that actually survive and reproduce. (2) Heritable variations allow some individuals to compete more successfully for space, food, and mates. (3) These successful individuals somehow pass the favorable characteristics to their offspring. (4) As a result, the favorable traits become more common in the next generation, and less successful traits become less common. This process of natural selection results in evolutionary change. Today, evolutionary biologists recognize that natural selection is just one of several potent evolutionary processes, as described in Chapter 21.

Over many generations, the evolutionary changes in a population may become extensive enough to produce a population of organisms that is distinct from its ancestors. Nevertheless, parental and descendant species often share many characteristics, allowing researchers to understand their relationships and reconstruct their shared evolutionary history, as described below and in Chapter 24. Starting with the first organized cells, this aspect of evolutionary change has contributed to the diversity of life that exists today.

Darwin and Wallace described evolutionary change largely in terms of how natural selection changes the commonness or rarity of particular variations over time. Their intellectual achievement was remarkable for its time. Although Darwin and Wallace understood the central importance of variability among organisms to the process of evolution, they could not explain how new variations arose or how they were passed to the next generation.

Mutations in DNA Are the Raw Materials That Allow Evolutionary Change

Today, we know that both the origin and the inheritance of new variations arise from the structure and variability of DNA, which is organized into functional units called **genes**. Each gene contains the code (that is, the instructions for building) for a protein molecule or one of its parts. Proteins are the molecules that establish the structures and perform important biological functions within organisms.

Variability among individuals—the raw material molded by evolutionary processes—arises ultimately through **mutations**, random changes in the structure, number, or arrangement of DNA molecules. Mutations in the DNA of reproductive cells (that is, sperm and eggs) may change the instructions for the development of offspring that the reproductive cells produce. Many mutations are of no particular value to individuals bearing them, and some turn out to be harmful. On rare occasions, however, a mutation is beneficial under the prevailing environmental conditions. Beneficial mutations increase the likelihood that individuals carrying the mutation will survive and reproduce. Thus, through the persistence and spread of beneficial mutations among individuals and their descendants, the genetic makeup of a population will change from one generation to the next.

Adaptations Enable Organisms to Survive and Reproduce in the Environments Where They Live

Favorable mutations may produce **adaptations**, characteristics that help an organism survive longer or reproduce more under a particular set of environmental conditions. To understand how organisms benefit from adaptations, consider an example from the recent literature on *cryptic coloration* (camouflage) in animals.



Wild rock dove



Photographs courtesy Deirrell Fowler, Tecumseh, Oklahoma

FIGURE 1.8 Artificial selection. Using artificial selection, pigeon breeders have produced more than 300 varieties of domesticated pigeons from ancestral wild rock doves (*Columba livia*).

Many animals have skin, scales, feathers, or fur that matches the color and appearance of the background in their environment, enabling them to blend into their surroundings. Camouflage makes it harder for predators to identify and then catch them—an obvious advantage to survival. Animals that are not camouflaged are often just sitting ducks.

The rock pocket mouse (*Chaetodipus intermedius*), which lives in the deserts of the southwestern United States, is mostly nocturnal (that is, active at night). At most desert localities, the rocks are pale brown, and rock pocket mice have sandy-colored fur on their backs. However, at several sites, the rocks—remnants of lava flows from now-extinct volcanoes—are black; here, the rock pocket mice have black fur on their backs. Thus, like the sandy-colored mice in other areas, they are camouflaged in their habitats, the types of areas in which they live (**Figure 1.9A**). Camouflage appears to be important to these mice because owls, which locate prey using their exceptionally keen eyesight, frequently eat nocturnal desert mice.

Examples of cryptic coloration are well documented in scientific literature, and biologists generally interpret them as adaptations that reduce the likelihood of being captured by a predator. Michael W. Nachman, Hopi E. Hoekstra, and their colleagues at the University of Arizona explored the genetic and evolutionary basis for the color difference between rock pocket mice that live on light and dark backgrounds. In an article published in 2003, they reported the results of an analysis of mice sampled at six sites in southern Arizona and New Mexico. In two regions (Pinacate, AZ, and Armendaris, NM), both light and dark rocks were present, allowing the researchers to compare mice that lived on differently colored backgrounds. Two other sites had only light rocks and sandy-colored mice.

A. Camouflage in rock pocket mice (*Chaetodipus intermedius*)

Sandy-colored mice are well camouflaged on pale rocks, and black mice are well camouflaged on dark rocks (top); but mice with fur that does not match their backgrounds (bottom) are easy to see.



B. Distributions of rock pocket mice with light and dark fur

At sites in Arizona and New Mexico, mouse fur color closely matched the color of the rocks where they lived. The pie charts show the proportion of mice with sandy-colored or black fur, N = the number of mice sampled at each site. The bars beneath the pie charts indicate the rock color.

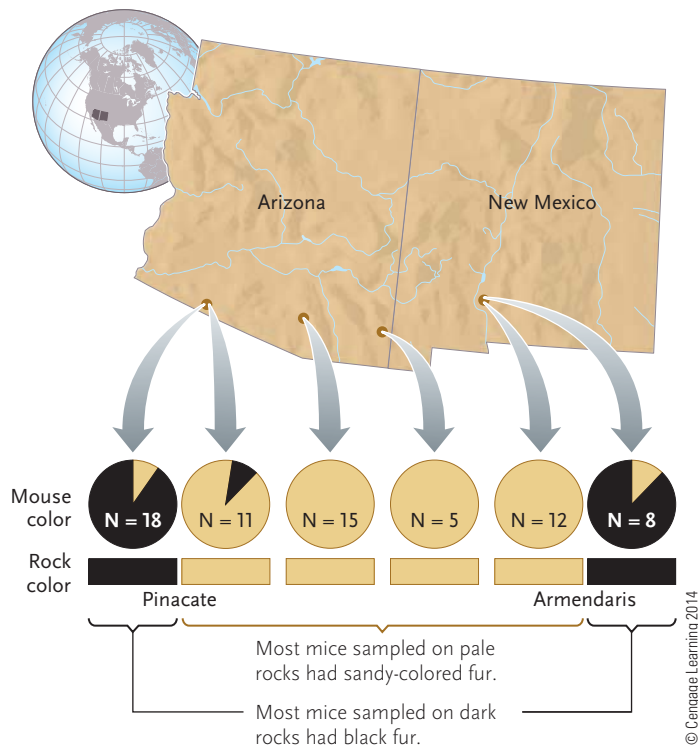


FIGURE 1.9 Adaptive coloration in rock pocket mice (*Chaetodipus intermedius*).

Nachman and his colleagues found that nearly all of the mice they captured on dark rocks had dark fur and that nearly all of the mice they captured on light rocks had light fur (**Figure 1.9B**). The researchers then studied the structure of *Mclr*, a gene known to influence fur color in laboratory mice; random mutations in this gene can produce fur colors ranging from light to dark in any population of mice, regardless of the habitat it occupies. The 17 black mice from Pinacate all shared certain mutations in their *Mclr* gene, which established four specific changes in the structure of the *Mclr* protein. However, none of the 12 sandy-colored mice from Pinacate carried these mutations. The exact match between the presence of the mutations and the color of the mouse strongly suggests that these mutations in the *Mclr* gene are responsible for the dark fur in the mice from Pinacate. These data on the distributions of light and dark mice coupled with analyses of their DNA suggest that the color difference is the product of specific mutations that were favored by natural selection. In other words, natural selection *conserved* random mutations that produced black fur in mice that live on black rocks.

Nachman's team then analyzed the *Mclr* gene in the dark and light mice from Armendaris and in the light mice at two intermediate sites. Because the mice in these regions also closely matched the color of their environments, the researchers expected to find the *Mclr* mutations in the dark mice but not in the light mice. However, none of the mice from Armendaris

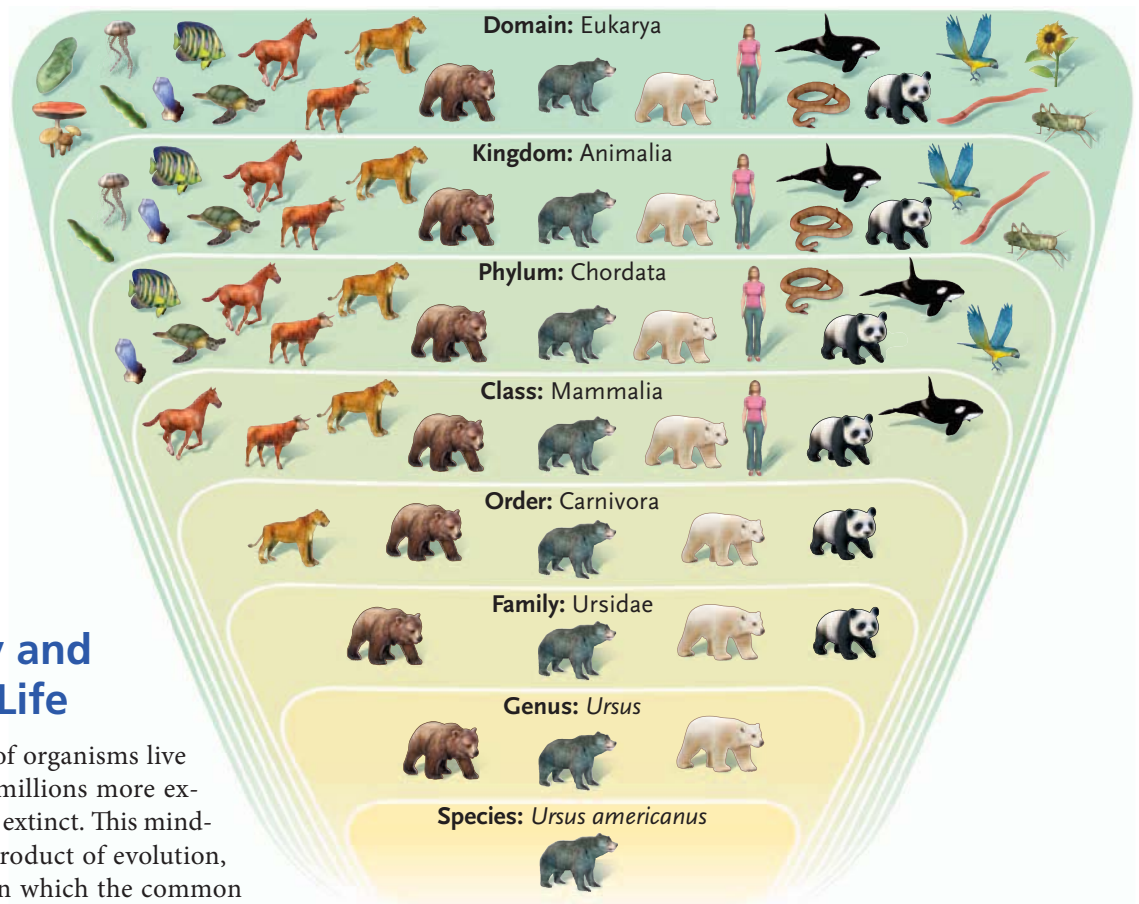
shared any of the mutations that apparently contribute to the dark color of mice from Pinacate. Thus, mutations in some other gene or genes, which the researchers have not yet identified, must be responsible for the camouflaging black coloration of mice that live on black rocks in Armendaris.

The example of an adaptation provided by the rock pocket mice illustrates the observation that genetic differences often develop between populations. Sometimes these differences become so great that the organisms develop different appearances and adopt different ways of life. If they become different enough, biologists may regard them as distinct types, as described in Chapter 22. Over immense spans of time, evolutionary processes have produced many types of organisms, which constitute the diversity of life on Earth. In the next section, we survey this diversity and consider how it is studied.

STUDY BREAK 1.2

1. What is the difference between artificial selection and natural selection?
2. How do random changes in the structure of DNA affect the characteristics of organisms?
3. What is the usefulness of being camouflaged in natural environments?

FIGURE 1.10 Traditional hierarchical classification. The classification of the American black bear (*Ursus americanus*) illustrates how each species fits into a nested hierarchy of ever-more inclusive categories. The following sentence can help you remember the order of categories in a classification, from *Domain* to *Species*: Diligent Kindly Professors Cannot Often Fail Good Students. © Cengage Learning 2014



1.3 Biodiversity and the Tree of Life

Millions of different kinds of organisms live on Earth today, and many millions more existed in the past and became extinct. This mind-boggling biodiversity, the product of evolution, represents the many ways in which the common elements of life have combined to survive and reproduce. To make sense of the past and present diversity of life on Earth, biologists analyze the evolutionary relationships of these organisms and use classification systems to keep track of them. As described in Chapter 24, the task is daunting, and there is no clear consensus on the numbers and kinds of divisions and categories to use. Moreover, our understanding of evolutionary relationships is constantly changing as researchers develop new analytical techniques and learn more about extinct and living organisms.

Researchers Traditionally Defined Species and Grouped Them into Successively More Inclusive Hierarchical Categories

Biologists generally consider the species to be the most fundamental grouping in the diversity of life. As described in Chapter 22, a **species** is a group of populations in which the individuals are so similar in structure, biochemistry, and behavior that they can successfully interbreed. Biologists recognize a **genus** (plural, *genera*) as a group of similar species that share recent common ancestry. Species in the same genus usually also share many characteristics. For example, a group of closely related animals that have large bodies, four stocky legs, long snouts, shaggy hair, non-retractable claws, and short tails are classified together in the genus *Ursus*, commonly known as bears.

Each species is assigned a two-part **scientific name**: the first part identifies the genus to which it belongs, and the second part

designates a particular species within that genus. In the genus *Ursus*, for example, *Ursus americanus* is the scientific name of the American black bear; *Ursus maritimus*, the polar bear, and *Ursus arctos*, the brown bear, are two other species in the same genus. Scientific names are always written in italics, and only the genus name is capitalized. After its first mention in a discussion, the genus name is frequently abbreviated to its first letter, as in *U. americanus*.

In a traditional classification, biologists first identified species and then grouped them into successively more inclusive categories (Figure 1.10): related genera are placed in the same **family**, related families in the same **order**, and related orders in the same **class**. Related classes are grouped into a **phylum** (plural, *phyla*), and related phyla are assigned to a **kingdom**. In recent years, biologists have added the **domain** as the most inclusive group.

Today Biologists Identify the Trunks, Branches, and Twigs on the Tree of Life

For hundreds of years, biologists classified biodiversity within the hierarchical scheme described above, mostly using structural similarities and differences as clues to evolutionary relationships. With the development of new techniques late in the twentieth century, biologists began to use the precise structure of DNA and other biological molecules to trace the evolutionary pathways