Biology

THE DYNAMIC SCIENCE 4e

RUSSELL HERTZ MCMILLAN

About the cover

The red salamander (*Pseudotriton ruber*) is common in cold, rocky springs and streams in wooded and open areas of the eastern United Sates. Adults sometimes inhabit moist sphagnum or soil under rocks or logs, leaf litter, and crevices adjacent to streams. Like all salamanders, *P. ruber* is predatory, typically feeding on invertebrate prey and on smaller salamanders.

Adults grow to 95–190 mm in total length. Although males may court and inseminate females in wet terrestrial habitats, red salamanders move to streams in the autumn to lay 30–130 eggs under submerged rocks and logs. Eggs hatch in late winter or spring, and the metamorphosis of larvae into adults occurs 1.5 to 3.5 years later.

Although not listed as threatened or endangered, many red salamander populations have suffered from habitat loss and degradation, largely attributable to acid drainage from coal mines, other forms of pollution, and the accumulation of silt in streams.

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Biology

The Dynamic Science

Fourth Edition

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***Biology: The Dynamic Science*, Fourth Edition**
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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.

Aaron Kinard

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 *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.

Courtesy of Beverly McMillan

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 eleventh 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.

Preface

Welcome to the fourth 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 previous editions, we have encapsulated the dynamic nature of biology in the fourth 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 three editions of this book provided students with the tools they need to learn fundamental biological concepts and processes. More important, the previous editions encouraged students to *think like scientists* by applying the process of science. 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 data. The many instructors and students who have used previous editions have generously provided valuable feedback that has allowed us to strengthen the elements that enhance student learning. We have also received comments from expert reviewers. As a result of these inputs, every chapter has been revised and updated with recent studies, including many based on genomic and proteomic analyses. In addition, the chapters in Unit One (Molecules and Cells) have been reorganized. This edition also includes new or modified illustrations and photos, as well as some new features.

The fourth edition of *Biology: The Dynamic Science* represents a fully integrated package of print and media that will appeal to today's students. Although the traditional format of the printed text can stand alone for both instructors and students, MindTap, the most engaging and easily personalized online solution in biology, enables instructors to deliver what they know is best for their students. MindTap offers an online version of the text, as well as before-class and in-class exercises, assignable and gradable homework exercises drawn from the book's content, and other resources and features that allow students to assess their learning as they progress through their study of biology.

Emphasizing the big picture . . .

In this textbook, we have applied our collective experience as teachers, researchers, and writers to create a readable and understandable foundation for students who choose to enroll in more advanced biology courses in the future. Where appropriate, we provide straightforward explanations of fundamental concepts from the evolutionary perspective that bind together all of the biological sciences. Recognizing that students in an introductory biology course face a potentially daunting quantity of ideas and information, we strive to provide an appropriate balance between factual and conceptual material, taking great care to provide clear explanations of how scientists draw conclusions from empirical data. Our approach helps students 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. With this edition, full integration with MindTap engages students with appealing and useful exercises that encourage them to learn biology by thinking like scientists.

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 knowledge with a critical eye.

In this book, we introduce students to a biologist's "ways of learning." 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, all of which are included in MindTap, 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 xiv.

- The chapter openers, titled *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 . . .* feature 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 titled *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.
- Most chapters include a short, boxed essay titled *Molecular Insights* (formerly called *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 *Molecular Insights* focus on a single study and include sufficient detail for their content to stand alone.
- Many chapters are further supplemented with one or more short, boxed essays called *Focus on Research.* Each essay focuses on one of three different aspects of research. *Focus on Research: Basic Research* essays describe how research has provided understanding of basic biological principles. *Focus on Research: Applied Research* essays describe research designed to solve practical problems in the world, such as those relating to health or the environment. *Focus on Research: Model 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 specific hypotheses and test them 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 light and electron microscopy, the polymerase chain reaction, making a knockout mouse, 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 and the fully integrated online resources critically important. From the first edition, our illustration program has provided an exceptionally clear supplement to the narrative in a style that is consistent throughout the book. Graphs

and anatomical drawings are annotated with interpretive explanations that lead students, step by step, through the major points they convey.

Over subsequent editions, we have enhanced the illustration program, focusing on features that reviewers and users of the book identified as the most useful pedagogical tools. For this most recent edition, we focused explicitly on helping students to think like scientists. A revised Figure 1.14 illuminates the intellectual steps that collectively lead researchers to new scientific discoveries. These steps—observation, hypothesis, prediction, experiment, and interpretation—represent the fundamentals of our "think like a scientist" theme in this book.

In revising the text, we reevaluated each illustration and photograph and made appropriate changes to improve their utility as teaching tools. New illustrations for the fourth edition were created in the same style as existing ones. In addition, some illustrations of key biological processes were recast as *Closer Look* figures in which a Summary and a concluding *Think Like a Scientist* question enhance student learning.

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 . . .

In the third edition we introduced an 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 end of *Experimental Research* figures, *Observational Research* figures, *Closer Look* figures, *Molecular Insights* boxes, and *Unanswered Questions*. In this new edition, *Experimental Research* figures and *Observational Research* figures include a new icon that identifies the particular step in the process of science that the *Think Like a Scientist* question addresses: Observe, Hypothesize, Predict, Experiment, or Interpret. (Sample shown.)

This edition also continues the popular *Think Outside the Book* active learning feature. *Think Outside the Book* activities have been designed to encourage students to explore biology directly or through electronic resources, working either individually or collaboratively.

Supplementary materials at the end of each chapter—all of which are fully integrated into MindTap—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.

Test Your Knowledge includes four 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) Multiple-choice questions (with answers in an appendix) focus on factual material; (2) *Discuss Concepts* questions involve open-ended issues 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; and (4) *Apply Evolutionary Thinking* questions ask students to answer a question in relation to the principles of evolutionary biology.

In this edition, *Test Your Knowledge* questions are organized according to Bloom's taxonomy into three sections: Remember/Understand, Apply/Analyze, and Evaluate/Create. This structure allows students to review the material in a sequence that moves from the basic knowledge of factual material to more challenging and sophisticated applications of that knowledge to novel situations.

Interpret the Data questions, highlighted in a distinctive format, help students develop analytical and quantitative skills by asking them to interpret graphical or tabular results of experimental or observational research studies for which the hypotheses and methods of analysis are presented.

Effectively introducing digital solutions into your classroom—online or in class—is now easier than ever . . .

The fourth edition of *Biology: The Dynamic Science* represents a fully integrated package of print and media, providing comprehensive learning tools and flexible delivery options. In preparing this edition we conducted extensive research to determine how instructors prefer to present online learning opportunities. The result of this research is a new MindTap course organized around the instructor's preferred workflow. Instructors can now select just the content they want to assign, chosen from a comprehensive set of learning materials provided with the course for each chapter. Many types of learning activities are assignable and offer students immediate feedback and automated instructor assessment.

Research also indicates that online content is most effective when it enhances conceptual understanding through the use of relevant applications. In this edition, we have developed three new assessable, online learning activities that align with important book features and provide students the opportunity to explore and practice biology the way scientists practice biology:

- The *Interpret the Data* feature at the end of every chapter is enhanced by an additional online exercise to further develop student quantitative analysis and mathematical reasoning skills.

altrendo images/Getty Images.

- Many *Experimental Research* and *Observational Research* figures now include an additional activity to help students engage with the scientific process.
- The end-of-chapter *Design an Experiment* feature is presented online as a guided learning activity that takes the student through the process of designing an experiment.

The *Instructor Resource Center* provides everything you need for your course in one place. This collection of lecture and class tools is available online for instructors only via www.cengage.com/login. There you can access and download PowerPoint presentations, images, the *Instructor's Manual,* videos, and more.

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.

Peter J. Russell Paul E. Hertz Beverly McMillan

New to This Edition

The enhancements we have made in the fourth 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. The new icon for *Think Like a Scientist* questions not only helps readers identify those questions easily, but it also helps students reinforce their understanding of the process of science.

We have also made important changes in coverage to follow recent scientific advances. In the third edition, we added a new Chapter 19, Genomes and Proteomes, that discusses methods of genomics and proteomics along with examples of new discoveries and insights. To reflect the importance of these approaches, genomics and proteomics coverage has been integrated throughout the book. In addition, 35 *Molecular Insights* boxes have been revised to include recently published research, and many of them focus on genomics or proteomics. Beyond these 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.

Chapter 1

In the introductory chapter, Section 1.1 (What is Life? Characteristics of Living Organisms) has been revised to provide a more detailed discussion of the function and transmission of genetic information in living systems; and the accompanying figure (Figure 1.4) provides a more accurate portrayal of nucleic acids and the flow of information from DNA to RNA to proteins. In addition, Section 1.4 (Biological Research) now has a more explicit discussion of the process of science, including revisions to Figure 1.14 (now a *Closer Look* figure), which introduces the new icon for *Think Like a Scientist* questions in *Experimental Research* figures and *Observational Research* figures. Finally, the introduction of genomics and proteomics has been refined, and systems biology is introduced (with a new Figure 1.17) as an inclusive approach for exploring complex biological phenomena.

Unit One: Molecules and Cells

Unit One has been reorganized. The former Chapter 4 (Energy, Enzymes, and Biological Reactions) is now Chapter 6, preceding Chapter 7 (Cellular Respiration: Harvesting Chemical Energy) and Chapter 8 (Photosynthesis) to provide a more logical conceptual flow of metabolism. The former Chapter 7 (Cell Communication) is now Chapter 9.

Chapter 2 (Life, Chemistry, and Water) has a new *Why it matters . . .* relating biology to underlying chemical reactions, a new subsection on molecule geometry and function in the cell, and a new *Unanswered Questions* essay on the effect of climate change on marine ecosystems.

Chapter 3 (Biological Molecules: The Carbon Compounds of Life) has molecular models added to Table 3.1 on functional groups and to Table 3.2 on major protein functions.

In Chapter 4 (Cells), Section 4.2 on Prokaryotic Cells has been reorganized into subsections on structure and organization, and evolutionary divergence of bacteria and archaea, and Section 4.3 on Eukaryotic Cells has added proteomics content in the endomembrane system discussion, updated discussion of the Golgi complex and vesicle traffic, and enhanced discussion of the movement of organelles and vesicles. A new *Molecular Insights* describes a genome-wide analysis study identifying human proteins that regulate secretion.

Chapter 5 (Membranes and Transport) adds the kiss-and-run model of exocytosis.

Chapter 7 (Cellular Respiration: Harvesting Chemical Energy) adds more examples of human disorders related to cellular respiration, discussion of evolution of mitochondria, and discussion of anaerobic respiration. A new Section 7.6 on Interrelationships of Catabolic and Anabolic Pathways combines material previously in earlier sections with new material to discuss how food substances feed into glycolysis, how biosynthetic pathways link to glycolysis and the citric acid cycle (with a new figure), and the regulation of cellular respiration (with a new figure). A new *Molecular Insights* describes experiments studying the mitochondrial proteome and its variation among organs and organisms.

In Chapter 8 (Photosynthesis), a new *Experimental Research* figure describes the Engelmann experiment. Discussion of the evolution of photosynthesis and cellular respiration has been enhanced. A new *Molecular Insights* describes proteomics experiments on the effect of water deficit on growth and photosynthesis in a C_3 plant.

Chapter 9 (Cell Communication) has expanded discussion of the different types of signaling along with an updated figure. Sections on receptor tyrosine kinases and G-protein–coupled receptors are now combined with new material on ligand-gated ion channels into a single section on signaling pathways triggered by surface receptors. Nitric oxide is added to the internal receptor section.

Chapter 10 (Cell Division and Mitosis) has enhanced discussion of chromosomes now including presentation of chromosome structure and levels of chromosome organization (including a figure) moved from Chapter 14 (DNA Structure and Replication). A new *Molecular Insights* describes proteomics experiments on the regulation of proteins in the cell cycle of humans.

Unit Two: Genetics

In Chapter 12 (Mendel, Genes, and Inheritance), the terms *gene marker, genetic marker,* and *DNA marker* are now introduced to relate to discussions later in the unit.

Chapter 13 (Genes, Chromosomes, and Human Genetics) adds discussions of pedigrees and pedigree analysis with four new figures, and of the usefulness of mitochondrial DNA analysis in genealogy and forensics. A new *Molecular Insights* describes experiments on the involvement of noncoding RNAs in X-chromosome inactivation.

Chapter 14 (DNA Structure and Replication) adds discussion of the loading and unloading of the sliding clamp in human DNA replication, a new figure and description of the replisome complex for DNA replication, discussion of the role of telomeres as chromosome caps, and a description of how newly replicated DNA is assembled into nucleosomes. Section 14.4 is retitled Repair of Errors in DNA to reflect the addition of new material on excision repair mechanisms, and a new figure on thymine dimers and their repair.

Chapter 15 (From DNA to Protein) now discusses Garrod's classic experiment in *Why it matters . . .* adds discussion of the coupling of transcription, pre-mRNA processing and export of mRNA from the nucleus, and adds new material on spontaneous and induced mutations and mutagens, transposable element content of genomes, and the types of changes in gene expression eukaryotic transposable elements can cause. A new *Molecular Insights* describes genomics/proteomics experiments on the effect of sleep–wake timing on gene expression.

In Chapter 16 (Regulation of Gene Expression), Section 16.2 on Regulation of Transcription in Eukaryotes is reorganized to present chromatin modification and methylation before the molecular details of transcription initiation at promoters. Discussion of DNA methylation and gene regulation is expanded, including analysis of DNA methylomes. New material is added on the interference of transcription by long noncoding RNAs (lncRNAs), on the cataloging of human promoters and enhancers by genome analysis, and on the role of alternative splicing in adjusting gene output to match physiological requirements. In Section 16.4, Genetic and Molecular Regulation of Development, the discussion of *Hox* genes is rewritten and expanded, and lncRNAs are added to the discussion of noncoding RNAs and their roles in development. Section 16.5, Genetics of Cancer, is changed to The Genetics and Genomics of Cancer to reflect added content. Discussion of genes involved in cancer is rewritten to include new knowledge from genomic approaches on the types of genes involved in cancer, and the cellular processes affected by mutations associated with cancer. Also added is discussion of cancer therapy and the prospect of personalized medicine, and how cancer genomic analysis identifies cancer subtypes. A new *Molecular Insights* describes experiments on the role of a key long noncoding RNA in cardiac development.

In Chapter 17 (Bacterial and Viral Genetics), a new *Molecular Insights* describes genomics/proteomics experiments that identified the largest known giant virus.

Chapter 18 is retitled DNA Technologies: Making and Using Genetically Altered Organisms, and Other Applications, to reflect a reorganization of the chapter around the theme of making and using genetically altered organisms for basic and applied research. The three main sections of the chapter are now Key DNA Technologies for Making Genetically Altered Organisms, Applications of Genetically Altered Organisms, and Other Applications of DNA Technologies (not involving genetically altered organisms). PCR is now emphasized more as a widely used technique, and Southern and northern blotting are no longer discussed. A new figure is added on making knockout mice by gene targeting, and a new *Focus on Research* box describes programmable RNA-guided genome editing based on CRISPR-Cas. The *Why it matters . . .* is new, discussing the relationship between historical genetics approaches to modern-day genomics approaches. A new *Molecular Insights* describes metabolomic experiments on the nutritional quality of genetically modified food.

In Chapter 19 (Genomes and Proteomes), lncRNAs are added to the discussions of important genome sequences, the ENCODE project is added to the discussion of the profile of the human genome, and tables are updated.

Unit Three: Evolutionary Biology

Chapter 20 (The Development of Evolutionary Thinking) has been revised to contextualize the study of evolution within the science process described in Chapter 1, and Figure 20.10 presenting Darwin's observations, hypotheses, and predictions has been restructured to reflect the process of science theme we have developed. In addition, the discussion of the fossil record has been updated to reflect new discoveries about the relationships of birds to non-avian dinosaurs, and Figure 20.13 now includes a phylogenetic tree to highlight when key adaptations arose. Chapter 20 also includes a new *Molecular Insights* on the genetics of dog domestication.

In Chapter 21 (Microevolution: Genetic Changes within Populations), the discussion of variation in DNA sequences now includes the importance of single-nucleotide polymorphisms in biological research. The *Focus on Research* box about the Hardy–Weinberg genetic equilibrium has been subdivided to make the steps in the analysis more explicit. The figure on the distribution of color and striping patterns in European garden snails (Figure 21.15) has been revised to emphasize the associations between snail phenotypes and habitat types. The chapter includes a new example of frequency-dependent selection, using flower color in a European orchid (Figure 21.16). In Table 21.2, we have added a column about the fitness consequences of each of the agents of evolution. Finally, Chapter 21 includes a new *Molecular Insights* about the genetic and physiological mechanisms that produce exaggerated horns in male rhinoceros beetles.

In Chapter 22 (Speciation), a new introduction to the discussion of reproductive isolation in Section 22.2 provides a broader context for the discussion of the mechanisms of

reproductive isolation. The discussion of parapatric speciation was deleted from Section 22.3 on the geography of speciation in favor of a more extended discussion of the possible consequences of secondary contact after a period of allopatry. The example of a hybrid zone between oriole *(Icterus)* species has been enhanced with additional text and a revised figure (22.12). The discussion of allopolyploidy and speciation in wheat has been updated with new genomic studies and a greatly revised figure (22.16). Chapter 22 includes a revised figure in the *Focus on Research* box about speciation in Hawaiian *Drosophila,* as well as a new *Molecular Insights* about the genetics of ecological and behavioral isolation between two *Drosophila* species.

In Chapter 23 (Paleobiology and Macroevolution), the table (Table 23.1) outlining geological time and the history of life has been consolidated and now includes more references to major geological events. The chapter also includes a revised discussion of biogeographical realms with a revised figure (23.10) based on a study published in 2013. The discussions of both adaptive radiations and mass extinctions have also been updated along with a new figure (23.14) showing the pattern of mass extinctions more explicitly. The discussion of feathers in non-avian dinosaurs and birds has been updated with new information, and a new figure (23.24) illustrates age-related changes in dinosaur plumage.

In Chapter 24 (Systematics and Phylogenetics: Revealing the Tree of Life), the taxonomic hierarchy is outlined in a new table (Table 24.1) that cross-references information in Figure 1.10. The discussion about reading a phylogenetic tree has been consolidated, and the accompanying figures have been combined into a *Closer Look* figure (24.2). The discussion of homology and homoplasy has been clarified. Chapter 24 also includes a new *Molecular Insights* (with accompanying phylogenetic tree) about the evolution of electric organs in fishes.

Unit Four: Biodiversity

In Chapter 25 (The Origin of Life), Section 25.1 on the formation of molecules necessary for life was revised to add material about what is needed to understand the origin of life, about questions asked in the scientific study of the origin of life, and about the possible role of alkaline hydrothermal vents in the origin of life. Section 25.2 on the origin of cells was largely rewritten, now to discuss the evolution of molecular replicators, the evolution of cellular membranes, and the evolution of biological energy sources, as well as adding to the discussion of prokaryotic cells as the first living cells.

Chapter 26 (Prokaryotes: Bacteria and Archaea) adds a discussion of microbiomes.

Chapter 27 (Protists) adds a discussion of the apicoplast and its origin. A new *Molecular Insights* describes experiments on two different types of bacteria associated with a cellular slime mold.

Chapter 28 (Seedless Plants) includes examples of comparative genomics that shed light on the evolution of vascular tissue in land plants and of new fossil finds that expand our understanding of land plant evolution. The chapter's new *Molecular Insights, Comparative Genomics Probes Plant Evolution,* reinforces these ideas. The chapter now concludes with a new section that surveys the ecological, economic, and research importance of seedless plants. New figures accompany chapter discussions of early adaptation for water transport and the evolutionary shift from homospory to heterospory.

Chapter 29 (Seed Plants) begins with a new *Why it matters . . .* that introduces students to the core concept that the evolution of the seed, together with pollen and pollination, was crucial in the radiation of vascular plants into nearly every land environment. A new Section 29.1, The Rise of Seed Plants, examines key innovations in the evolution of the seed; new line art illustrates key stages hypothesized for one of those innovations, the evolution of the ovule. This new section provides the conceptual foundation for subsequent sections on gymnosperms and angiosperms, both of which have been reorganized and expanded. Section 29.3, on angiosperms, includes new subsections that underscore the adaptive roles of flowers, double fertilization, fruits and seeds. Expanded coverage in Section 29.4 (previously 29.3), Insights from Plant Genome Research, includes the hypothesized role of whole genome duplication in plant polyploidy and examples of how genome sequencing is advancing research on the biology and evolutionary relationships of various seed plant lineages. A new, concise Section 29.5, Seed Plants and People, reminds students of the major roles of seed plants in human affairs. A new *Molecular Insights* describes insights that are emerging from the sequencing of the loblolly pine genome.

Revisions to Chapter 30 (Fungi) include a discussion of the proposed new fungal phylum Cryptomycota and a new *Molecular Insights, Researching Relationships of "Hidden Fungi."* Much of the third edition's discussion of mycorrhizae now appears in Chapter 34 on plant nutrition. A new concluding section discusses the effects of fungi on ecosystems and human endeavors.

Changes to Chapter 31 (Animal Phylogeny, Acoelomates, and Protostomes) include an updated description of how the molecular phylogeny for animals was constructed. The chapter now also includes descriptions of a recently discovered predatory sponge, all-female species of bdelloid rotifers, and a revised analysis of annelid systematics to reflect recent research. The discussion of insects includes a new description of the evo–devo origin of insect wings. Although *Molecular Insights* addresses the same topic (relationships among arthropods) as in prior editions, it is now based on research published in 2010 and includes a revised phylogenetic tree for arthropods.

In Chapter 32 (Deuterostomes: Vertebrates and Their Closest Relatives), revisions include an expanded discussion of conodont elements and of placoderms as a paraphyletic group. The chapter also includes a greatly expanded discussion of the origin of limbs with a completely revised figure (32.21). The discussion of amniote relationships, including the phylogenetic tree (Figure 32.24), reflects new insights into the relationships of turtles to archosaurs and recognizes the newly defined group

Archelosauromorpha. The phylogenetic tree for primates (Figure 32.34) now includes characters that distinguish clades, and the discussion of human evolution now includes a description of the Denisovans and an enhanced hominin timeline (Figure 32.39).

Unit Five: Plant Structure and Function

This edition's chapters on plant anatomy and physiology also have been significantly revised, updated, and reorganized. In Chapter 33 (The Plant Body), a new *Why it matters . . .* introduces the main chapter topic using the historical domestication of grasses (rice, wheat, corn) to underscore the relevance of plant parts to human concerns. Sections on root and shoot systems are reordered, with root systems considered first (Section 33.3) followed by primary shoot systems (Section 33.4). A new *Molecular Insights* features current research on the complex genetic events governing the formation of secondary cell walls.

In Chapter 34 (Transport in Plants), a new *Why it matters . . .* uses the example of the centuries-old Angel Oak on Johns Island in South Carolina to introduce transport in plants. The discussion of water potential is revised for clarity, with new subsections providing a more straightforward presentation on solute and pressure potential, turgor pressure, and wilting. Section 34.2, formerly Transport in Roots, is now titled Roots: Moving Water and Minerals into the Plant. A new Figure (34.7) provides an enhanced visual to support the text discussion of the Casparian strip. Section 34.3, Transport of Water and Minerals in the Xylem, now includes a subsection on effects of humidity, temperature, and wind on transpiration. The functioning and regulation of stomata are now considered in a separate section (Section 34.4). A new *Molecular Insights, Going with the Phloem,* looks at recent experiments exploring the role of the transcription factors called NAC proteins in shaping the development of sieve-tube elements.

Enhancements to Chapter 35 (Plant Nutrition) include new photographs (Figure 35.2) to illustrate a range of nutrient deficiency symptoms in plants. A new subsection discusses the use of fertilizers to remedy nutrient deficiencies in soil. Section 35.2 on soil characteristics now includes the role of weathering in soil formation. New subsections clearly distinguish the effects of organic and inorganic components of soils and discuss the role of proper soil management (including no-till farming) in sustainable agriculture. Section 35.3, Root Adaptations for Obtaining and Absorbing Nutrients, now presents much of the discussion of mycorrhizae that previously was in Chapter 30 (Fungi). The subsection on nitrogen fixation now includes a concise description of denitrification.

In Chapter 36 (Reproduction and Development in Flowering Plants), Section 36.2 on the formation of flowers and gametes now includes a new subsection on evolutionary trends in flower structure with accompanying photographs that allow students to readily visualize and compare key differences in flower structure. Two other new subsections expand the chapter's coverage of fruit diversity and seed dispersal mechanisms. Section 36.4, Asexual Reproduction of Flowering Plants, provides expanded examples of vegetative reproduction. The discussion of tissue culture methods emphasizes somatic embryogenesis, including the creation of artificial seeds.

Chapter 37 (Plant Signals and Responses to the Environment) also features important revisions and additions. The introduction to plant hormones in Section 37.1 is reorganized to consider auxins, cytokinins, and gibberellins, in that order. It also includes strigolactones (SLs) as a major plant hormone family, with accompanying line art reinforcing the varied functions of SLs in enhancing nutrient access and optimizing the growth of shoot and root parts. The subsection on ethylene now includes the triple response in seedling growth. A brief comparison of constitutive and inducible defenses is added to Section 37.2, Plant Chemical Defenses. One new subsection, Defensive Chemicals Reflect the Coevolution of Plants, Pathogens, and Herbivores, discusses bioactive specialized compounds including phytoalexins, plant alkaloids, terpenes, and phenolics. Another new subsection on inducible responses to specific threats introduces pattern recognition receptors and their role in detecting pathogen-associated molecular patterns (PAMPs). A new *Molecular Insights* discusses the recent work of Chunyang Wang and colleagues in exploring the evolution of hormone signaling in plants.

Unit Six: Animal Structure and Function

Chapter 38 (Introduction to Animal Organization and Physiology) expands discussion of anchoring junctions, tight junctions, and gap junctions, and of the basics of epithelial structure and structure, including new discussion and a figure on pseudostratified columnar epithelium. A new Molecular Insights describes miRNA regulation of epithelial cell differentiation in the lung and its relationship to lung cancer. In the presentation of homeostasis, a new subsection discusses how set points can change due to biorhythms or altered environmental conditions.

Chapter 39 (Information Flow and the Neuron) adds information about the proteomic analysis of chemical synapses, and the discussion of equilibrium potential now includes presentation of the Nernst equation.

Chapter 40 (Nervous Systems) adds discussion of the evolutionary changes in brain regions, brain size, and relative size of brain regions in vertebrate brains, and expanded description of the knee-jerk reflex. A new *Molecular Insights* describes experiments on sex differences in the neural connections of the human brain.

Chapter 41 (Sensory Systems) adds a new subsection on the evolutionary history of olfactory receptor genes revealed by bioinformatics analysis of genomes. A new *Molecular Insights* describes experiments on taste neuron changes associated with the emergence of an adaptive behavior in cockroaches.

Chapter 42 (The Endocrine System) adds discussion of nongenomic action of some steroid hormones. A new *Molecular Insights* describes experiments on the fear-enhancing effects of some oxytocin receptors in mice.

Chapter 43 (Muscles, Bones, and Body Movements) expands the discussion of synovial joints. A new *Molecular Insights* describes aspects of the genetics of bone formation learned from analysis of the elephant shark genome.

Chapter 44 (The Circulatory System) adds a figure on the control of red blood cell production.

Chapter 45 (Defenses against Disease) adds a new flowchart figure of antibody-mediated and cell-mediated immune responses, and adds discussion of microbiome composition in preventing pathogen attack. A new *Molecular Insights* describes genomics experiments revealing the unique immune system of the Atlantic cod.

In Chapter 46 (Gas Exchange: The Respiratory System), a new *Molecular Insights* describes genomics-based experiments on the evolution of altitude adaptation in Tibetans.

Chapter 47 (Animal Nutrition) adds discussion of gut microbiomes and their roles in digestion and nutrition. A new *Molecular Insights* describes experiments on the association of intestinal bacterial populations with obesity in humans.

Chapter 48 (Regulating the Internal Environment) expands discussion of temperature regulation in endotherms. A new *Molecular Insights* describes experiments on the involvement of miRNAs with the development of polycystic kidney disease.

In Chapter 49 (Animal Reproduction), discussion of hormonal regulation of male reproductive functions is enhanced and includes a new replacement figure.

In Chapter 50 (Animal Development), a new *Molecular Insights* describes experiments showing an essential role of protein O-mannosylation in embryonic development.

Unit Seven: Ecology and Behavior

In Chapter 51 (Ecology and the Biosphere), the chapter opener is now more focused on natural climate cycles and less on disastrous weather events. The chapter also includes expanded discussions of positive feedback loops between climate warming and melting of permafrost in tundra, as well as more detailed descriptions of deep-sea environments. A new *Molecular Insights* describes the genetic basis of adaptation to extreme cold in polar octopuses.

In Chapter 52 (Population Ecology), we have updated Figures 52.22 and 52.23 on human population growth. We have subdivided the *Focus on Research* box into sections to clarify the take-home message about the effects of predation on guppy life histories. The chapter also includes a new *Molecular Insights* on the construction of a life table for ant colonies.

Chapter 53 (Population Interactions and Community Ecology) includes new examples of Batesian mimicry (between birds and insects) and fundamental and realized niches (cane toads) with dramatic new figures. In addition, the figure about primary succession (53.28) has been converted into the *Closer Look* format.

Chapter 54 (Ecosystems and Global Change) has undergone substantial revision. The distinction between detrital and grazing food webs has been eliminated, and the discussion of biological magnification (previously a *Focus on Research* box) has been tightened and incorporated into the text. Ecological pyramids are now represented in a single figure (54.8) instead of three; and new figures on the effects of temperature and precipitation on primary productivity (54.4), seasonal changes in primary productivity (54.5), the greenhouse effect (54.15), rising carbon dioxide levels and global temperature (54.16), and anthropogenic nitrogen fixation (54.17) have been added. In addition, Section 54.4 (now titled Human Activities and Anthropogenic Global Change) includes expanded and updated discussions of disruptions to the carbon and nitrogen cycles and a completely new discussion of the impact of global change on ecosystems, including ocean acidification, declining primary productivity, and dead zones in shallow marine environments. The *Molecular Insights* box has been condensed.

Chapter 55 (Biodiversity and Conservation Biology) includes updated and expanded discussions of overfishing, invasive species (updated Figure 55.10 on hemlock woolly adelgids), dam removals, amphibian declines, and vulture mortality in South Asia. It also features a new example of habitat fragmentation with a new figure (55.6). Section 55.3 (now titled Ecosystem Services That Biodiversity Provides) includes discussions of provisioning, regulating, and support services. Section 55.4 (Which Species and Ecosystems Are Most Threatened by Human Activities?) now includes a discussion of the *IUCN Red List of Threatened Species* and an accompanying new figure (55.13). Section 55.5 includes a new discussion on the cost of preserving biodiversity. The *Molecular Insights* box on DNA barcoding has been updated and includes a new figure, and the *Focus on Research* box about population viability analysis has been tightened and condensed.

Chapter 56 (Animal Behavior) has added emphasis on cost/benefit analyses in the chapter opener. The discussion of honeybee communication has been updated to reflect new research on the waggle dance (with revisions to Figure 56.19). We have also substantially revised the discussion of altruism, inclusive fitness, and kin selection to include Hamilton's inequality as a means of predicting altruistic behavior; and the discussion of haplodiploidy and eusociality has been expanded to include alternative hypotheses for the evolution of this complex behavior.

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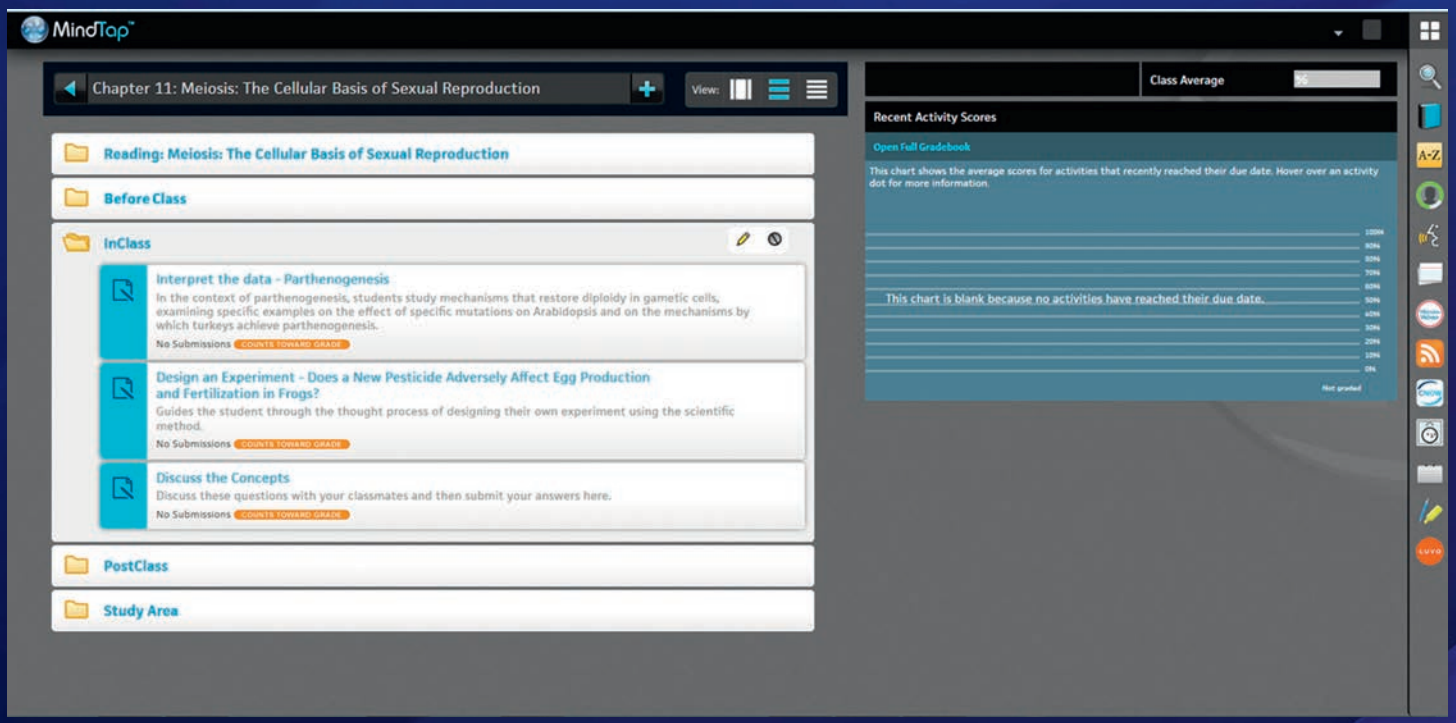

▲ Elevate learning and conceptual understanding with assignable and gradeable exercises that build on material presented in the text. Fully editable content delivery options are organized into categories to match course workflow. The InClass folder is expanded to show the pre-loaded content in this category.

Science as a Process

Immerse students in the process of doing biology, while building skills students need to succeed in more advanced courses.

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Science as a Process is emphasized throughout the ► text. *Research Figures* provide information about how biologists formulate and test specific hypotheses by gathering and interpreting data.

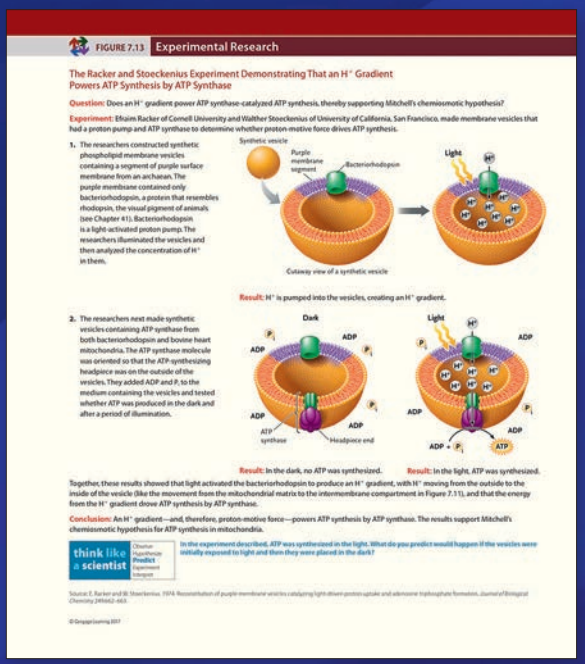


FIGURE 7.13 Experimental Research

The Racker and Stoeckenius Experiment Demonstrating That an H^+ Gradient Powers ATP Synthesis by ATP Synthase

Question: Does an H^+ gradient power ATP synthase-catalyzed ATP synthesis, thereby supporting Mitchell's chemiosmotic hypothesis?

Experiment: Efraim Racker of Cornell University and Walther Stoeckenius of University of California, San Francisco, made membrane vesicles that had a proton pump and ATP synthase to determine whether proton-motive force drives ATP synthesis.

1. The researchers constructed synthetic phospholipid membrane vesicles containing a segment of purple surface membrane from an archaean. The purple membrane contained only bacteriorhodopsin, a protein that resembles rhodopsin, the visual pigment of animals (see Chapter 41). Bacteriorhodopsin is a light-activated proton pump. The researchers illuminated the vesicles and then analyzed the concentration of H^+ in them.

Synthetic vesicle

Purple membrane segment

Bacteriorhodopsin

Light

Cutaway view of a synthetic vesicle

Result: H^+ is pumped into the vesicles, creating an H^+ gradient.

2. The researchers next made synthetic vesicles containing ATP synthase from both bacteriorhodopsin and bovine heart mitochondria. The ATP synthase molecule was oriented so that the ATP-synthesizing headpiece was on the outside of the vesicles. They added ADP and P_i to the medium containing the vesicles and tested whether ATP was produced in the dark and after a period of illumination.

Dark

Light

ATP synthase

Headpiece end

Result: In the dark, no ATP was synthesized.

Result: In the light, ATP was synthesized.

Together, these results showed that light activated the bacteriorhodopsin to produce an H^+ gradient, with H^+ moving from the outside to the inside of the vesicle (like the movement from the mitochondrial matrix to the intermembrane compartment in Figure 7.11), and that the energy from the H^+ gradient drove ATP synthesis by ATP synthase.

Conclusion: An H^+ gradient—and, therefore, proton-motive force—powers ATP synthesis by ATP synthase. The results support Mitchell's chemiosmotic hypothesis for ATP synthesis in mitochondria.

think like a scientist — Observe, Hypothesize, Predict, Experiment, Interpret

In the experiment described, ATP was synthesized in the light. What do you predict would happen if the vesicles were initially exposed to light and then they were placed in the dark?

Source: E. Racker and W. Stoeckenius. 1974. Reconstitution of purple membrane vesicles catalyzing light-driven proton uptake and adenosine triphosphate formation. *Journal of Biological Chemistry* 249:662–663.

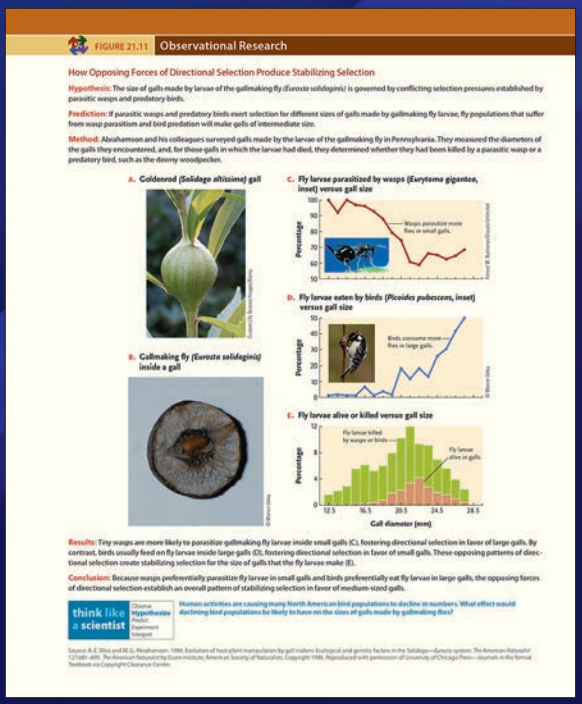


FIGURE 21.11 Observational Research

How Opposing Forces of Directional Selection Produce Stabilizing Selection

Hypothesis: The size of galls made by larvae of the gallmaking fly (*Eurosta solidaginis*) is governed by conflicting selection pressures established by parasitic wasps and predatory birds.

Prediction: If parasitic wasps and predatory birds exert selection for different sizes of galls made by gallmaking fly larvae, fly populations that suffer from wasp parasitism and bird predation will make galls of intermediate size.

Method: Abrahamson and his colleagues surveyed galls made by the larvae of the gallmaking fly in Pennsylvania. They measured the diameters of the galls they encountered, and, for those galls in which the larvae had died, they determined whether they had been killed by a parasitic wasp or a predatory bird, such as the downy woodpecker.

A. Goldenrod (*Solidago altissima*) gall

B. Gallmaking fly (*Eurosta solidaginis*) inside a gall

C. Fly larvae parasitized by wasps (*Eurytoma gigantea*, inset) versus gall size

Percentage

Wasps parasitize more flies in small galls.

D. Fly larvae eaten by birds (*Picoides pubescens*, inset) versus gall size

Percentage

Birds consume more flies in large galls.

E. Fly larvae alive or killed versus gall size

Percentage

Fly larvae killed by wasps or birds

Fly larvae alive in galls

12.5 16.5 20.5 24.5 28.5

Gall diameter (mm)

Results: Tiny wasps are more likely to parasitize gallmaking fly larvae inside small galls (C), fostering directional selection in favor of large galls. By contrast, birds usually feed on fly larvae inside large galls (D), fostering directional selection in favor of small galls. These opposing patterns of directional selection create stabilizing selection for the size of galls that the fly larvae make (E).

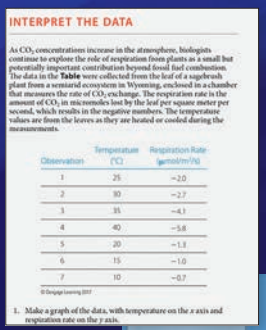
Conclusion: Because wasps preferentially parasitize fly larvae in small galls and birds preferentially eat fly larvae in large galls, the opposing forces of directional selection establish an overall pattern of stabilizing selection in favor of medium-sized galls.

think like a scientist — Observe, Hypothesize, Predict, Experiment, Interpret

Human activities are causing many North American bird populations to decline in numbers. What effect would declining bird populations be likely to have on the sizes of galls made by gallmaking flies?

Source: A. E. Weis and W. G. Abrahamson. 1986. Evolution of host-plant manipulation by gall makers: Ecological and genetic factors in the *Solidago*–*Eurosta* system. *The American Naturalist* 127:681–695. The American Naturalist by Essex Institute, American Society of Naturalists. Copyright 1986. Reproduced with permission of University of Chicago Press—Journals in the format Textbook via Copyright Clearance Center.

▲ Apply the Process of Science: ***Think Like a Scientist*** questions throughout the text ask students to apply what they have learned beyond the material presented in the book. **New** icon on selected figures relates the questions to steps in the scientific process. **Selected *Think Like a Scientist* exercises are assignable and gradeable in MindTap!**



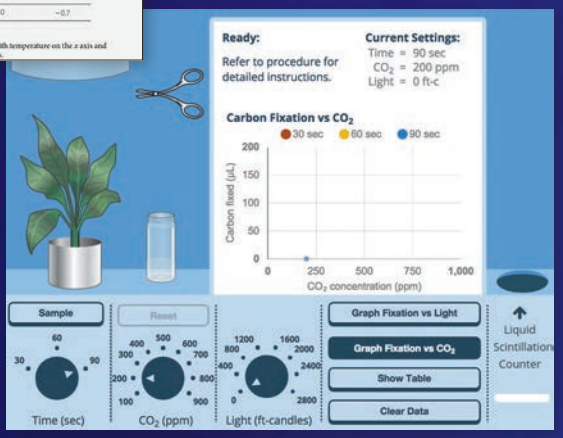
INTERPRET THE DATA

As CO_2 concentrations increase in the atmosphere, biologists continue to explore the role of respiration from plants as a small but potentially important contribution beyond fossil fuel combustion. The data in the **Table** were collected from the leaf of a sagebrush plant from a semiarid ecosystem in Wyoming, enclosed in a chamber that measures the rate of CO_2 exchange. The respiration rate is the amount of CO_2 in micromoles lost by the leaf per square meter per second, which results in the negative numbers. The temperature values are from the leaves as they are heated or cooled during the measurements.

Observation	Temperature (°C)	Respiration Rate (μmol/m^2/s)
1	25	−2.0
2	30	−2.7
3	35	−4.1
4	40	−5.8
5	20	−1.1
6	15	−1.0
7	10	−0.7

1. Make a graph of the data, with temperature on the *x* axis and respiration rate on the *y* axis.

◄ Build Quantitative Skills: ***Interpret the Data*** exercises in every chapter develop quantitative analysis and mathematical reasoning skills. **Exercises are assignable and gradeable in MindTap!**



Ready:

Refer to procedure for detailed instructions.

Current Settings:
Time = 90 sec
CO_2 = 200 ppm
Light = 0 ft-c

Carbon Fixation vs CO_2

30 sec 60 sec 90 sec

Carbon fixed (µL)

CO_2 concentration (ppm)

Sample

Reset

Time (sec)

CO_2 (ppm)

Light (ft-candles)

Graph Fixation vs Light

Graph Fixation vs CO_2

Show Table

Clear Data

Liquid Scintillation Counter

▲ Virtual Biology Laboratory (VBL) enables students to "do" science by acquiring data, performing experiments, and using that data to explain biological concepts or phenomena.

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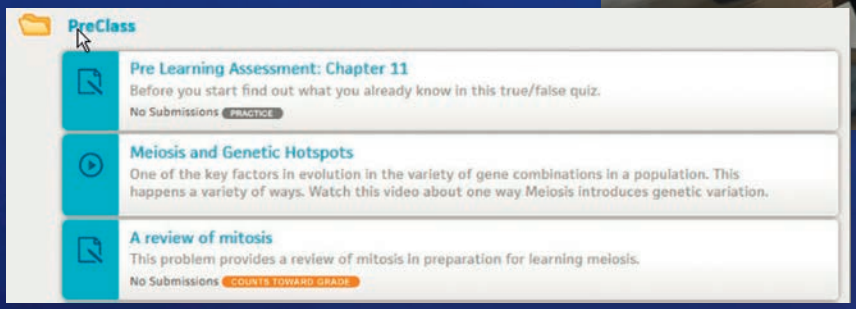
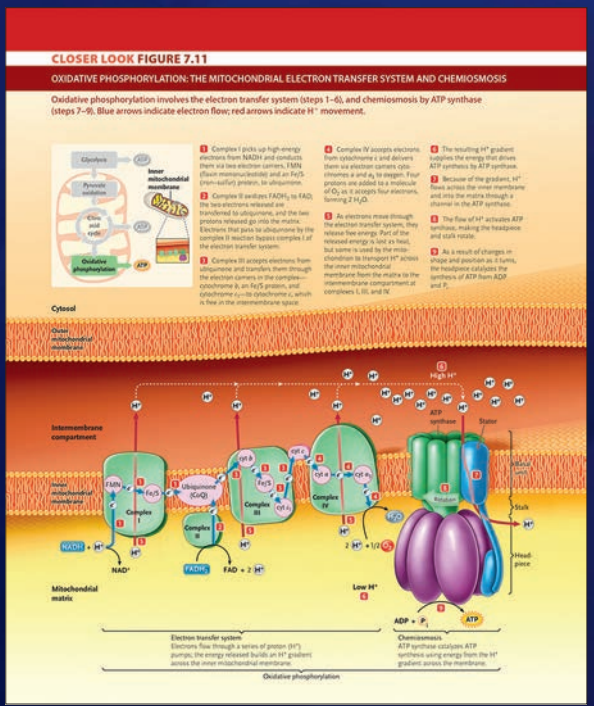


Straightforward explanations and carefully developed illustrations are followed by extensive opportunity



▲ Spectacular illustrations such as this *Closer Look* figure help students visualize complex processes. Numbered step-by-step explanations lead students through all the major concepts.

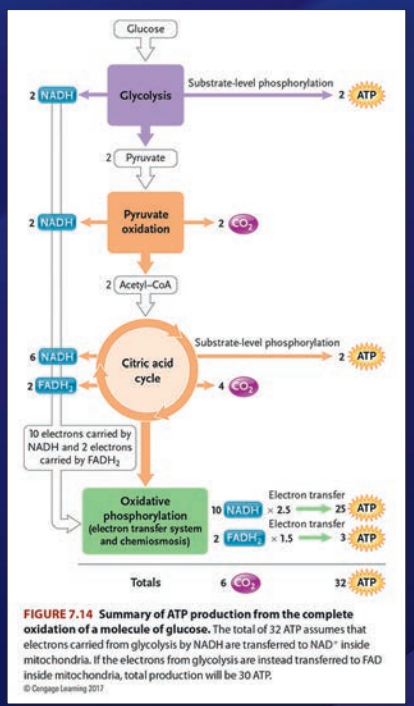


FIGURE 7.14 Summary of ATP production from the complete oxidation of a molecule of glucose. The total of 32 ATP assumes that electrons carried from glycolysis by NADH are transferred to NAD+ inside mitochondria. If the electrons from glycolysis are instead transferred to FAD inside mitochondria, total production will be 30 ATP.

▲ Summary figures help students see the big picture and understand important connections.

Full student engagement. On these two pages, take a tour of how you can design a dynamic learning path for students to help them learn important concepts. Our case example is from Chapter 7: Cellular Respiration: Harvesting Chemical Energy.

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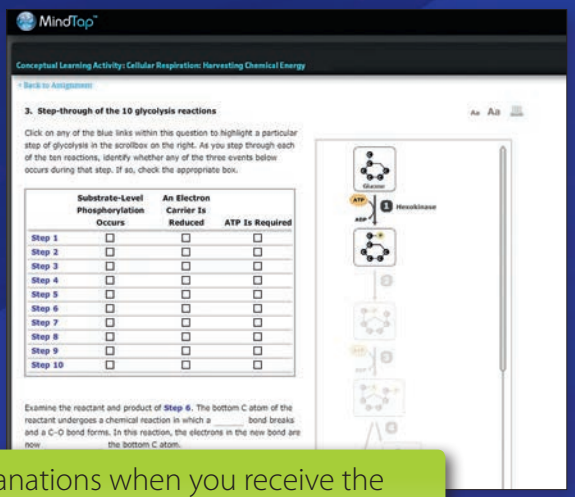
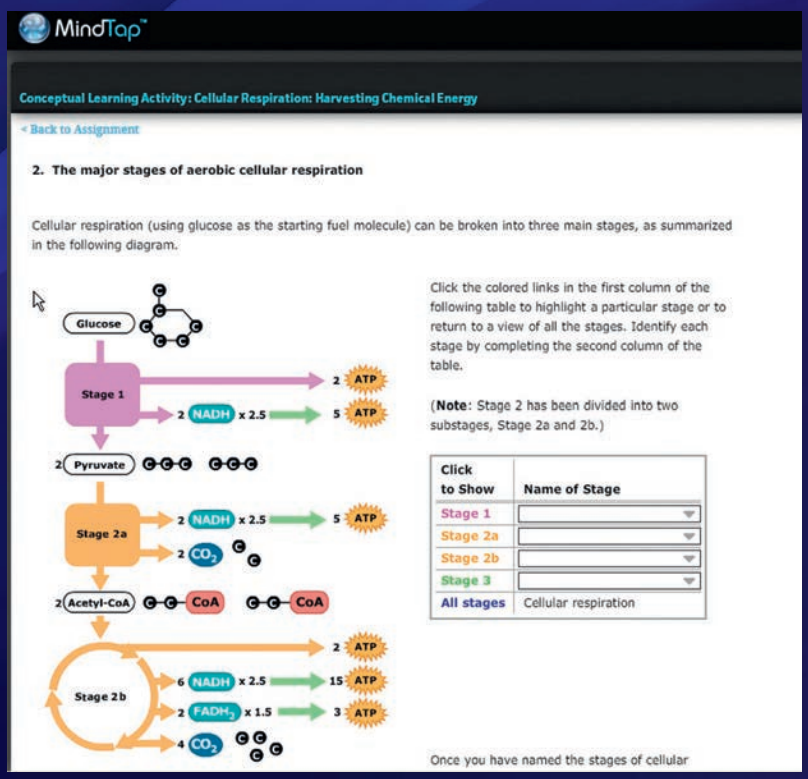


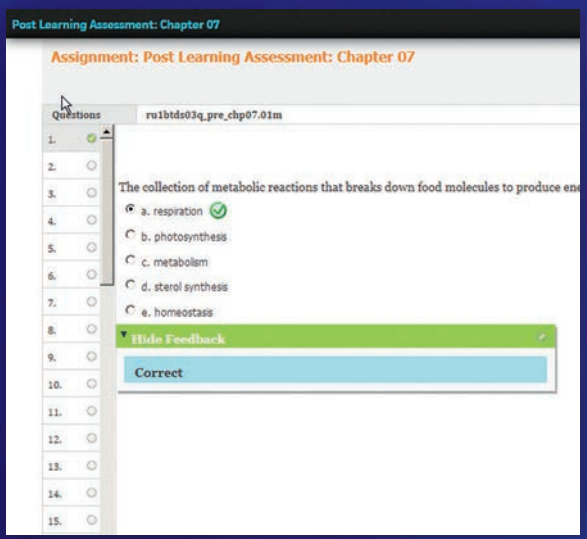
Engage with your students during class. **We provide a collection of dynamic activities. Or (of course!) insert your own content. Assess student understanding on a topic during class with interactive figures and immediate feedback with explanations.** ▶

"The explanations when you receive the wrong answer on a homework question were really good and helped me understand many concepts that I didn't originally understand."

—Timothy, California State University of Northridge

for reinforcement and practice. Sample content for learning about Cellular Respiration is shown below.





▲ Post Learning Assessments **offer students opportunities for more practice before a full chapter test. Practice Tests are assignable and gradeable in MindTap!**

◀ Conceptual exercises **in MindTap, repeatable in alternate versions, help students learn the material. Exercises are assignable and gradeable in MindTap!**

Active Learning

Features that engage your students in the process of learning because an engaged student is a successful student.

Molecular Insights

Genomics of Breast Cancer: How does binding of estrogen receptor β to the genome affect breast cancer progression?

The **Figure** shows an X-ray mammogram of a breast with cancer. Breast cancer is the leading cause of death among women in the United States and globally. About 50–70% of breast cancers are hormone-responsive, meaning that they need the female steroid hormone estrogen for the involved cells to grow and proliferate. Estrogens play a crucial role in regulating cell growth and differentiation in the mammary gland. In both normal and mammary gland cancer cells, estrogens act by binding to two specific steroid hormone receptors, estrogen receptors α and β (ERα and ERβ). Once activated by the binding of estrogen, these receptors are transcription factors, regulatory molecules that bind to the control regions of particular genes in the genome to alter those genes' expression, by turning them on or off, or increasing or decreasing their expression. (Expression of genes in this context means transcription, the copying of a gene's DNA sequence into a messenger RNA [mRNA] sequence; see Chapter 1 for an overview, and see Chapter 15 for detailed discussion.) Subsequent translation of the mRNA generates the protein encoded by the gene (see Chapters 1 and 15). Both ERs have similar DNA-binding domains (see Figure 9.15), and both can bind to the conserved DNA control sequence, 5'-GGTCAnnnTGACC-3', where "n" is any DNA nucleotide.

The two ERs may be present in the same cell. They have specific, often opposite functions, with ERα typically stimulating cell proliferation, and ERβ being inhibitory to cell proliferation. In breast cancer, ERβ often is lost, which removes its inhibitory effects, thereby allowing progression of the cancer via the effects of estrogen-bound ERα on gene expression. An important goal, therefore, is to understand where activated ERβ binds in the genome so as to determine the roles of this receptor in estrogen signaling and breast cancer.

Research Question

What are the genomic targets of activated ERβ in hormone-responsive breast cancer cells?

Experiments

Collaborating researchers in Italy, Germany, and the United States used genomics approaches to answer the question. They started with a human breast cancer cell line that is hormone-responsive and expresses ERα but not ERβ (ERα+ ERβ−). They genetically engineered those cells engineered to produce a cell line that expresses both ERα and ERβ (ERα+ ERβ+).

The researchers compared estrogen-stimulated expression from genes to which ERβ can bind in ERα+ ERβ+ vs. ERα+ ERβ− cells. They identified 921 genes whose expression was differentially regulated in the two cell types, meaning that their expression was the ER–DNA complex precipitates it. After removing the proteins, the sequences of the DNA they were bound to the ER is determined using next-generation sequencing, a technique in which many short segments of DNA are sequenced in parallel. (Next-generation sequencing is discussed in Chapter 19.) The researchers also analyzed gene expression (transcription) on a genomics scale (discussed in Chapter 19) to determine the similarities and differences in the two cell lines.

Results

The effect of estrogen on growth of hormone-responsive ERα+ ERβ+ and ERα+ ERβ− cells was compared. The results showed that the expression of ERβ in the ERα+ ERβ+ cells brought about a large reduction in cell proliferation compared to ERα+ ERβ−, which were not expressing ERβ.

ChIP-Seq analysis of estrogen-stimulated cells identified 5,196 binding sites in the genome for ERβ, 1,516 binding sites for ERα, and 4,506 binding sites to which both ERβ and ERα bind. Summing, there are 9,702 genomic binding sites ERβ, and 6,024 genomic binding sites for ERα.

▲ Molecular Insights boxes in each chapter describe how molecular tools allow scientists to answer questions that they could not have posed even 30 years ago. Most *Molecular Insights* focus on a single study and include sufficient detail for its content to stand alone. 25 new *Molecular Insights* boxes are focused on genomics or proteomics.

STUDY BREAK 8.2

1. What is the difference in function between the chlorophyll *a* molecules in the antenna complexes and the chlorophyll *a* molecules in the reaction centers of the photosystems?
2. How is NADPH made in the linear electron flow pathway?
3. What is the difference between the linear electron flow pathway and the cyclic electron flow pathway?

▲ Study Break questions at the end of every section in a chapter encourage students to pause and think about the material just encountered before moving to the next section. Answers to Study Break questions are provided in Appendix A.

THINK OUTSIDE THE BOOK

A number of human genetic diseases result from mutations that affect mitochondrial function. Collaboratively or individually, find an example of such a disease and research how the genetic mutation disrupts mitochondrial function and leads to the disease symptoms.

▲ Think Outside the Book activities help students think analytically and critically as they explore the biological world, either on their own or as part of a team.

Unanswered Questions explore important unresolved issues identified by experts in the field and describe cutting-edge research that will advance knowledge in the future. *Think Like a Scientist* questions encourage students to think critically about the research projects described. ▼

Unanswered Questions

What is the role of gene duplication in the evolution of plant diversity?

What is the genetic basis of the origin of new and complex structures, such as the flower, during the course of evolution? One important factor is gene duplication, thought to be one of the driving forces behind the increase in organismal complexity that we see with evolution. When a plant gene is duplicated, initially there are two identical copies with identical functions (called "redundancy"); often over time one of the copies either is eliminated or becomes nonfunctional, so that the original condition of one gene is restored. But sometimes, through the process of mutation and sequence divergence, the two copies take on different functions. They may divide the functions of the original single gene between them ("subfunctionalization"), or one of the copies may take on entirely new functions, leaving the other copy to perform the original function ("neofunctionalization"). It is this last possibility—the origin of new gene functions after duplication—that is thought to provide the raw material for the origin of new plant structures such as the flower.

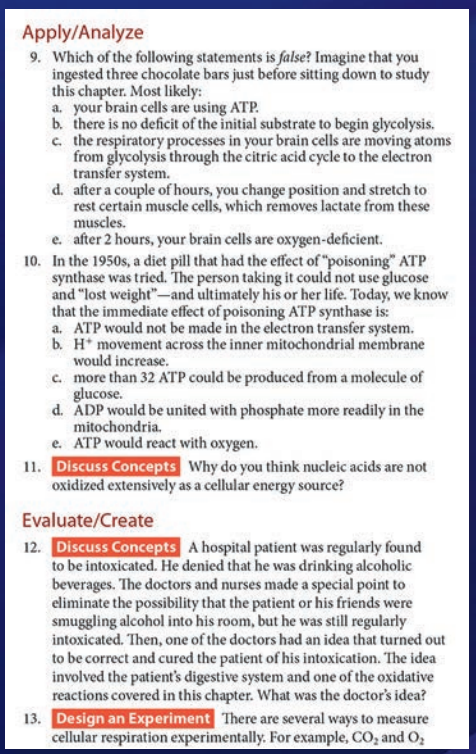
Like all gymnosperms, the ancestors of angiosperms produced separate cones with male and female reproductive structures, whereas flowers produce both male and female reproductive organs surrounded by a novel structure unique to flowers, the sterile *perianth* (sepals and petals). What genetic changes occurred in proto-angiosperms that allowed for the development of the complex bisexual flower and the perianth? Of course we cannot look at the genomes of the extinct angiosperm ancestors. However, by comparing the genomes of extant gymnosperms and angiosperms we can identify key flower development genes that are found only in angiosperms. In *Arabidopsis thaliana*, *APETALA1 (AP1)* and *SEPALLATA (SEP)* genes are required for proper flower formation. If *AP1* genes are eliminated, the plants will not form flowers. If *SEP* genes are eliminated, the plants form structures similar to flowers but with all the floral organs replaced by tiny leaves. *AP1* and *SEP* genes are found only in flowering plants; combined with the observation that these genes are required to form flowers, this suggests that they may have played a role in the evolution of the flower.

AP1 and *SEP* genes appear to have arisen by way of two duplications from a third gene group (*AGL6*) that is found in both gymnosperms and angiosperms. Along with the B- and C-function genes of the ABC model, these genes belong to the MADS-box family of transcription factors, members of which play key roles throughout plant development. Repeated duplication during the course of plant evolution has led to an increase in the number of these regulatory genes from 1 in algae to over 100 in *Arabidopsis*; the proliferation of these key developmental regulators may be one of the driving forces behind the increase in complexity from algae to angiosperms, and is likely to have played a role in the origin of the flower. Thus, duplications in these genes led to the origin in gymnosperms of the B- and C-function genes, which in gymnosperms appear to play a role in specifying reproductive organ identity that is carried into the angiosperms. In contrast, later duplications, coinciding with the origin of the angiosperms, led to the establishment of the *AP1* and *SEP* gene lineages. These angiosperm-specific genes are required for flower formation, and may have been critical, in particular, in the origin of the flower-specific perianth.

think like a scientist If the A function of the ABC model is not found in any species outside the mustard family, explain how the "BCE" model can still account for the formation of four different types of floral organs.

Amy Litt is on the faculty of the Department of Botany and Plant Sciences at the University of California, Riverside. Her main interests lie in the evolution of plant form and how changes in gene function during the course of plant evolution have produced novel plant forms and functions—particularly new flower and fruit morphologies.

Courtesy of Amy Litt



Apply/Analyze

9. Which of the following statements is *false*? Imagine that you ingested three chocolate bars just before sitting down to study this chapter. Most likely:
   a. your brain cells are using ATP.
   b. there is no deficit of the initial substrate to begin glycolysis.
   c. the respiratory processes in your brain cells are moving atoms from glycolysis through the citric acid cycle to the electron transfer system.
   d. after a couple of hours, you change position and stretch to rest certain muscle cells, which removes lactate from these muscles.
   e. after 2 hours, your brain cells are oxygen-deficient.
10. In the 1950s, a diet pill that had the effect of "poisoning" ATP synthase was tried. The person taking it could not use glucose and "lost weight"—and ultimately his or her life. Today, we know that the immediate effect of poisoning ATP synthase is:
    a. ATP would not be made in the electron transfer system.
    b. H^+ movement across the inner mitochondrial membrane would increase.
    c. more than 32 ATP could be produced from a molecule of glucose.
    d. ADP would be united with phosphate more readily in the mitochondria.
    e. ATP would react with oxygen.
11. **Discuss Concepts** Why do you think nucleic acids are not oxidized extensively as a cellular energy source?

Evaluate/Create

12. **Discuss Concepts** A hospital patient was regularly found to be intoxicated. He denied that he was drinking alcoholic beverages. The doctors and nurses made a special point to eliminate the possibility that the patient or his friends were smuggling alcohol into his room, but he was still regularly intoxicated. Then, one of the doctors had an idea that turned out to be correct and cured the patient of his intoxication. The idea involved the patient's digestive system and one of the oxidative reactions covered in this chapter. What was the doctor's idea?
13. **Design an Experiment** There are several ways to measure cellular respiration experimentally. For example, CO_2 and O_2

▲ End-of-Chapter review questions focus on both factual and conceptual questions. Now organized according to **Bloom's Taxonomy.**

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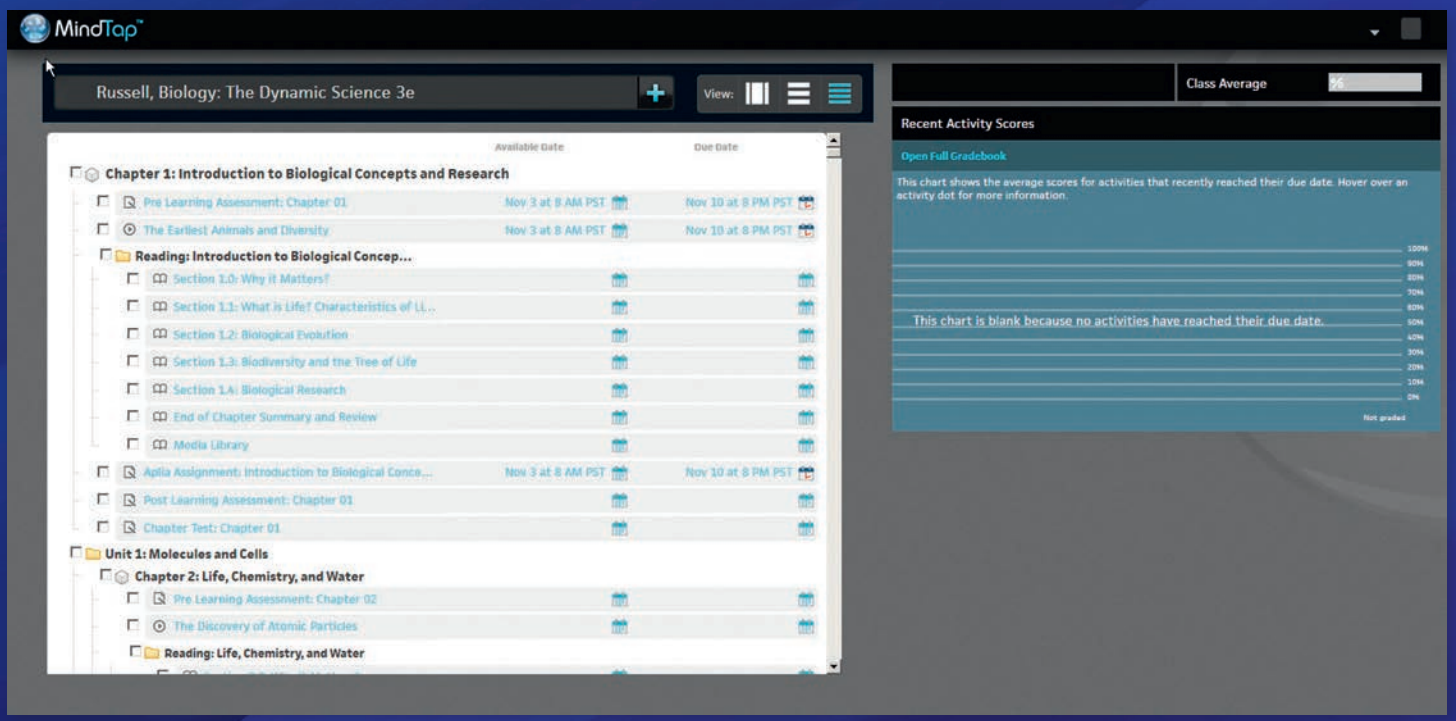

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Appendix A: Answers A-1

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Glossary G-1

Index I-1

Introduction to Biological Concepts and Research

1

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

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

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.

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

1.1 What Is Life? Characteristics of Living Organisms

Picture a tarantula on a rock, waiting patiently for a food item to wander within its reach **(Figure 1.1).** You know that the tarantula is alive and that the rock is not. At the atomic and molecular levels, however, the differences between them blur. Tarantulas, 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 tarantula 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 diverse 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, aspects of their structure and function may 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 specialized 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 Genetic Information That Governs Their Structure and Function

The most fundamental and important molecule that distinguishes living organisms from nonliving matter is **deoxyribonucleic acid (DNA).** DNA is a large, double-stranded, helical

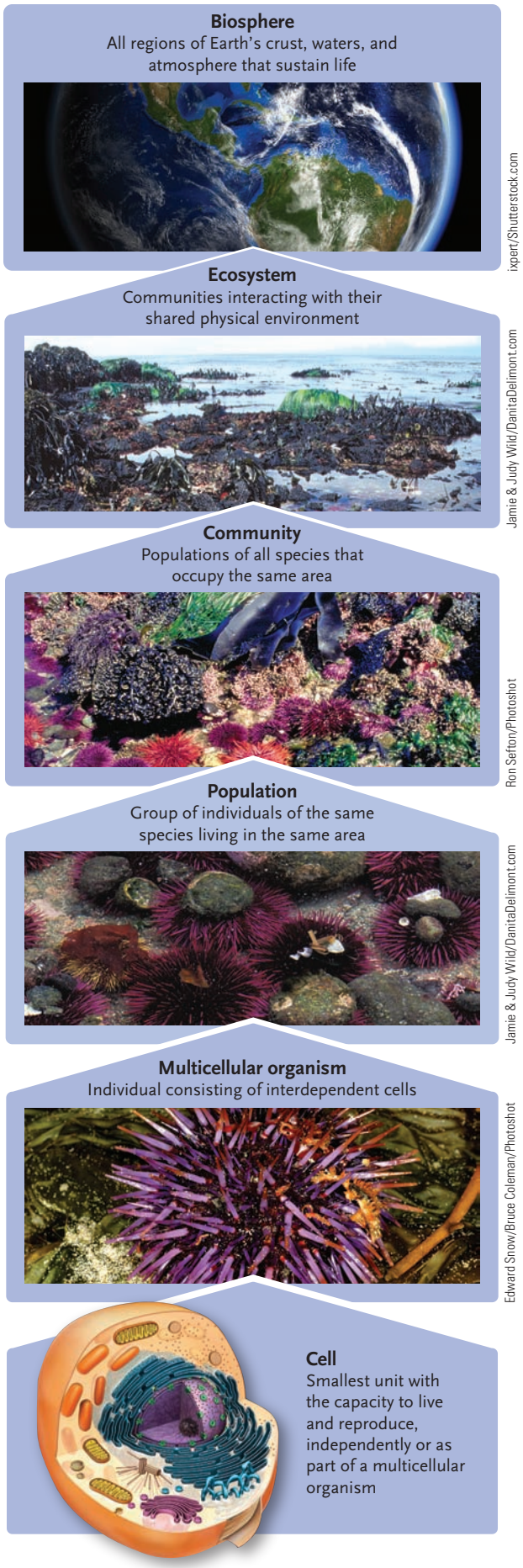


FIGURE 1.2 The hierarchy of life. Each level in the hierarchy of life exhibits emergent properties that do not exist at lower levels. The middle four photos depict a rocky intertidal zone on the coast of Washington State.

molecule that contains instructions for assembling a living organism from simpler molecules **(Figure 1.3A).** The two strands in a molecule of DNA each consist of a chain of chemical building blocks called **nucleotides.** The four different nucleotides present in DNA are commonly identified by the first letters of their chemical names: A, T, G, and C. (The structures of nucleotides and how they are organized in DNA are discussed in Section 3.5.) Nucleotides in one DNA strand chemically bond with nucleotides in the other DNA strand to form the double-helical structure of the molecule **(Figure 1.3B).** All of the DNA in the cells of a living organism constitutes its **genome,** which contains the genetic information that makes each organism unique. Genetic information is encoded in the sequence of nucleotides in an organism's DNA, just as this book conveys information in sequences of letters that make up words and sentences.

Genes are particular regions of the genome where specific nucleotide sequences encode instructions that cells use to build **ribonucleic acid (RNA)** molecules and **proteins.** The molecules produced from these instructions fold into specific three-dimensional shapes, and the shape of each protein or RNA molecule determines how it will function within the cell.

The process by which information encoded in genes guides the production of RNA molecules and proteins is called **gene expression.** The expression of a protein-encoding gene involves two steps **(Figure 1.4).** First, information in the nucleotide sequence of one of the gene's DNA strands is copied into a

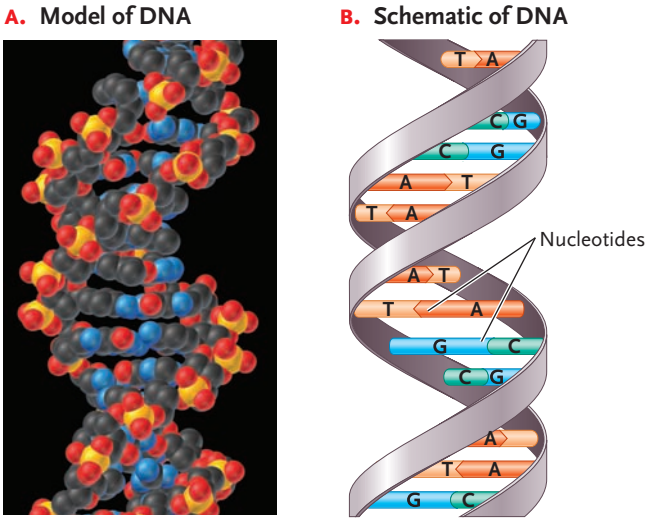


FIGURE 1.3 Deoxyribonucleic acid (DNA). (A) A computer-generated model of DNA illustrates that it is made up of two strands twisted into a double helix. **(B)** A schematic diagram shows how nucleotides on the two strands bind to each other.

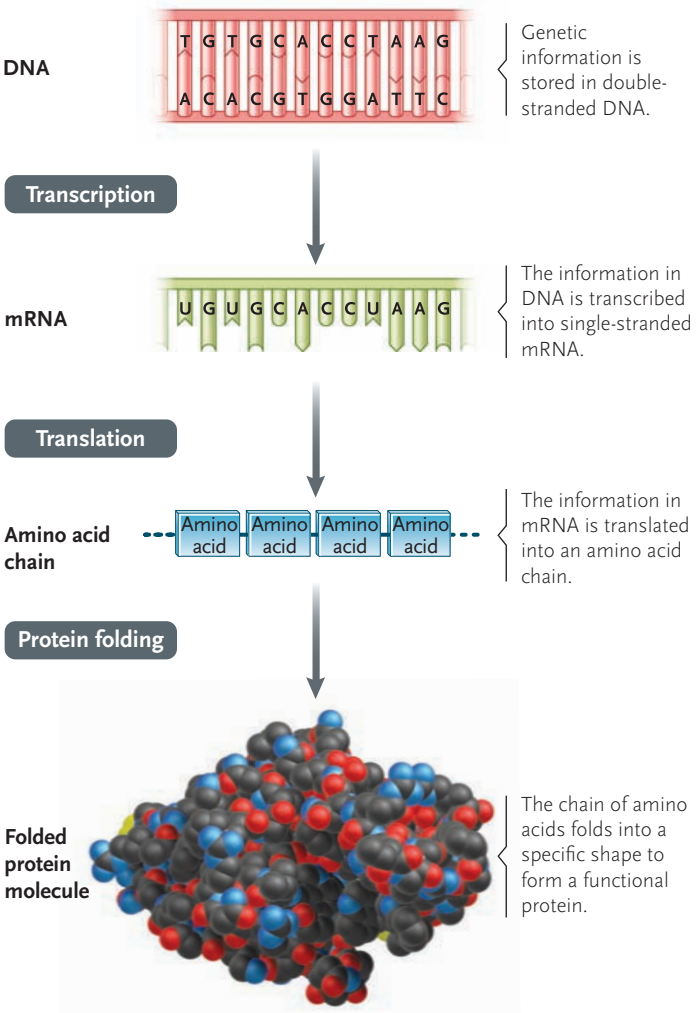


FIGURE 1.4 The pathway of information flow in living organisms. Information stored in DNA is transcribed to mRNA, which is then translated into a chain of amino acids. The amino acid chain folds to assume the functional structure of the protein. The protein shown here is lysozyme, a bacterial-wall digesting enzyme that is found in nasal mucus, tears, and other body secretions.

specific type of RNA molecule, **messenger RNA (mRNA),** which carries the instructions for building the protein. This step is called **transcription** because the information in one type of nucleic acid (DNA) is *transcribed* to another type of nucleic acid (RNA). Second, information in the nucleotide sequence carried by the messenger RNA is converted into a sequence of amino acids that makes up a protein molecule. This step is called **translation** because the nucleotide sequence in the mRNA is *translated* into a sequence of amino acids, producing a protein, an entirely different type of molecule. Translation is carried out on **ribosomes,** roughly spherical particles that are abundant in the cytoplasm. Ribosomes act as molecular machines that catalyze the assembly of amino acid chains.

The amino acid sequence of a protein determines how it folds into its functional structure. Thus, the different nucleotide sequences of genes produce mRNA molecules with different nucleotide sequences, which, in turn, guide the production of proteins with different amino acid sequences. (Transcription and translation are discussed in detail in Chapter 15.) Genes that do not encode proteins are transcribed to produce RNA molecules, but rather than being translated to produce a protein, those RNA molecules themselves fold into shapes that enable them to perform functions like regulating the expression of other, protein-encoding genes.

We can think of the genes within a genome as blueprints for the life of the organism: each protein or RNA product of a gene is a molecular tool that the organism uses to stay alive, grow, and reproduce. All of the ways that frogs differ from oak trees or from human beings result from differences in the genetic instructions encoded in the unique DNA sequences of these very different organisms, which in turn cause their cells to produce different proteins and RNA molecules. The human genome contains about 20,500 genes that encode proteins, and at least 20,000 other genes that encode RNA molecules. Together, these genes encode all of the molecular tools that perform all of the functions of human cells—and they determine how those cells combine together to form larger, multicellular structures like the tissues and organs of the human body.

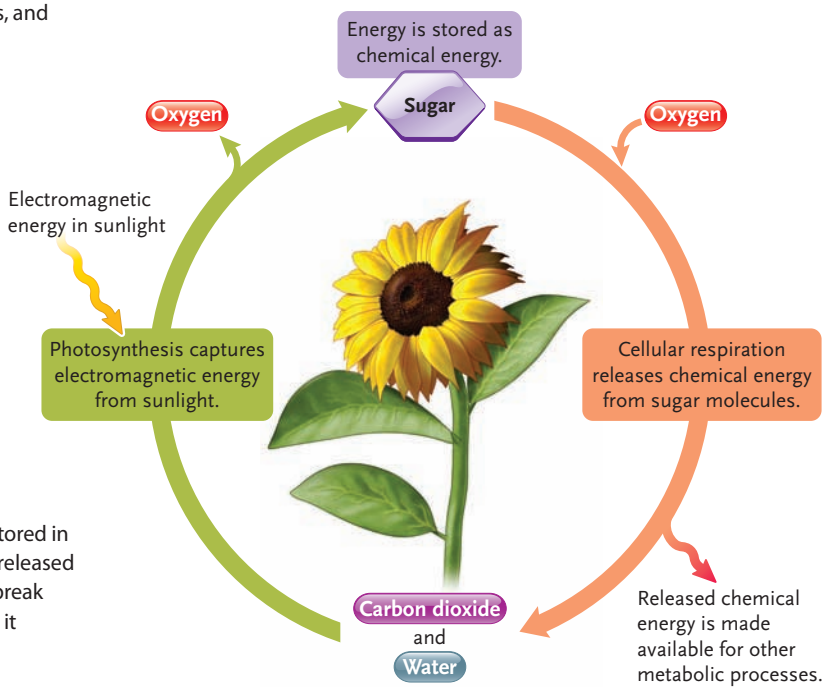


FIGURE 1.5 Metabolic activities. Photosynthesis converts the electromagnetic energy in sunlight into chemical energy, which is stored in sugars and starches built from carbon dioxide and water; oxygen is released as a by-product of the reaction. Cellular respiration uses oxygen to break down sugar molecules,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

Living Organisms Engage in Metabolic Activities

Some genes in all organisms code for molecules responsible for **metabolism** (described in Chapters 7 and 8), 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 temperature, 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).

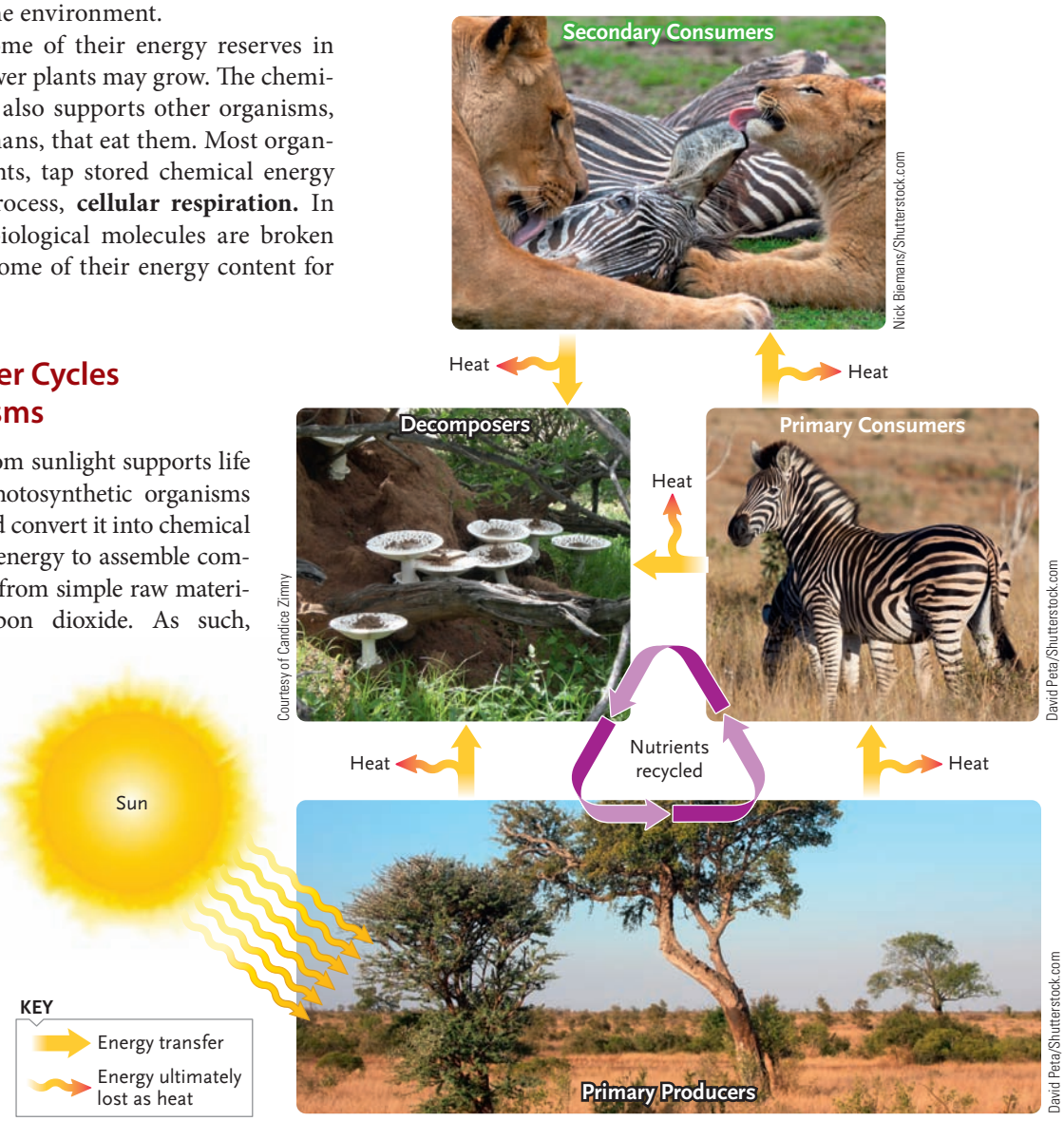


FIGURE 1.6 Energy flow and nutrient recycling. In most ecosystems, energy flows from the Sun to producers to consumers to decomposers. On the African savanna, the Sun provides energy to grasses (producers); zebras (primary consumers) then feed on the grasses before being eaten by lions (secondary consumers); 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.

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 secrete 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 state 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

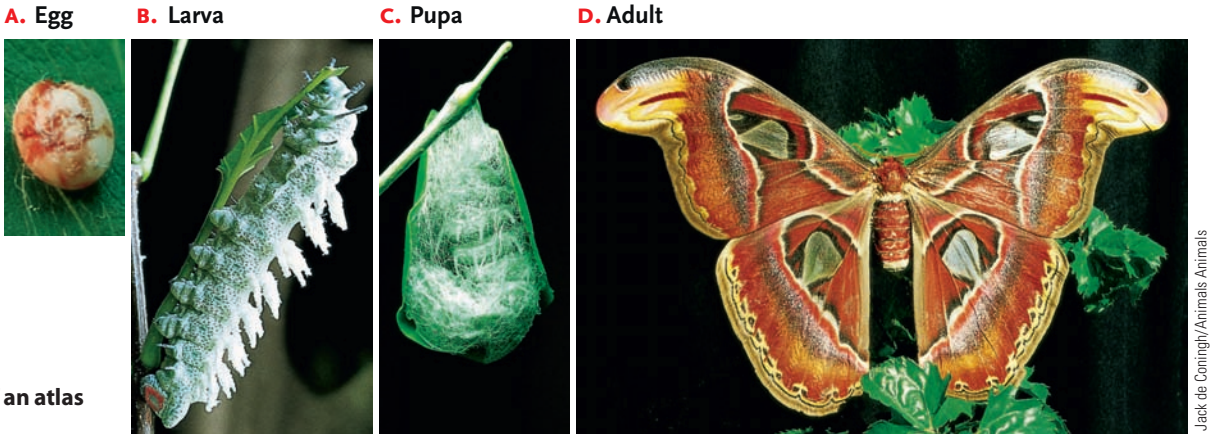
Humans and all other organisms are part of an unbroken chain of life that began at least 3.5 billion years ago. This chain continues today through **reproduction,** the process by which parents produce offspring. Offspring generally resemble their parents because the parents pass copies of their DNA—with 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.

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 often inherited by their offspring. Our awareness



Jack de Coningh/Animals Animals

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

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?

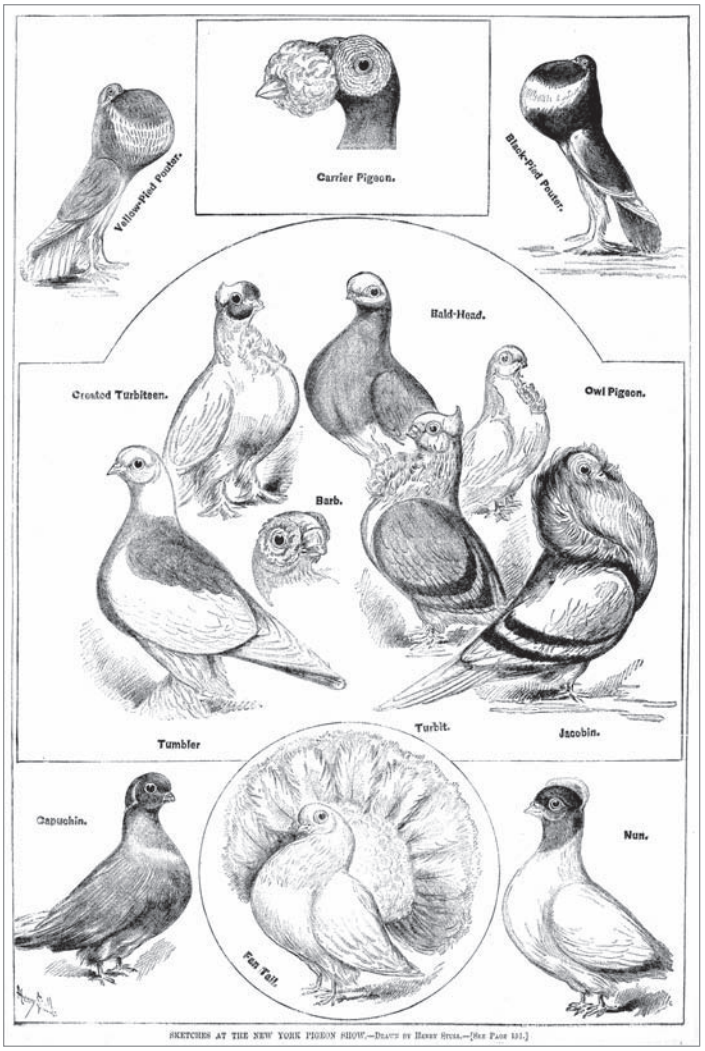
1.2 Biological Evolution

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 Populations of 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 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.**



(A) Granger, NYC — All rights reserved

FIGURE 1.8 Artificial selection. This lithograph, published in an American newspaper, illustrates breeds that were exhibited at the New York Pigeon Show in 1879. Darwin studied the inheritance of strange new characteristics in similar pigeon breeds.

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 both coding and noncoding segments of DNA. 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. 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.

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 the melanocortin 1 receptor gene *(Mc1r),* which influences 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. (Variations in this gene are also responsible for differences in hair and skin color in humans, and many are associated with an increased risk of developing skin cancer.) The 17 black mice from Pinacate all shared certain mutations in their *Mc1r* gene, which established four specific changes in the structure of the Mc1r protein. However, none of the 12 sandy-colored mice from

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.

Hopi Hoekstra, Harvard University

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.

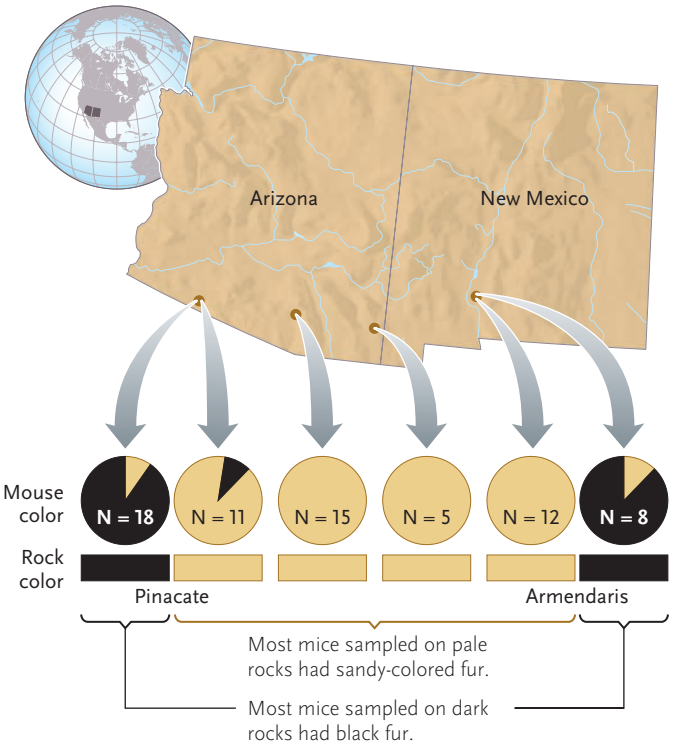


FIGURE 1.9 Adaptive coloration in rock pocket mice *(Chaetodipus intermedius)*.

Pinacate carried these mutations. The exact match between the presence of the mutations and the color of the mice strongly suggests that these mutations in the *Mc1r* 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 *Mc1r* 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 *Mc1r* 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?

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,