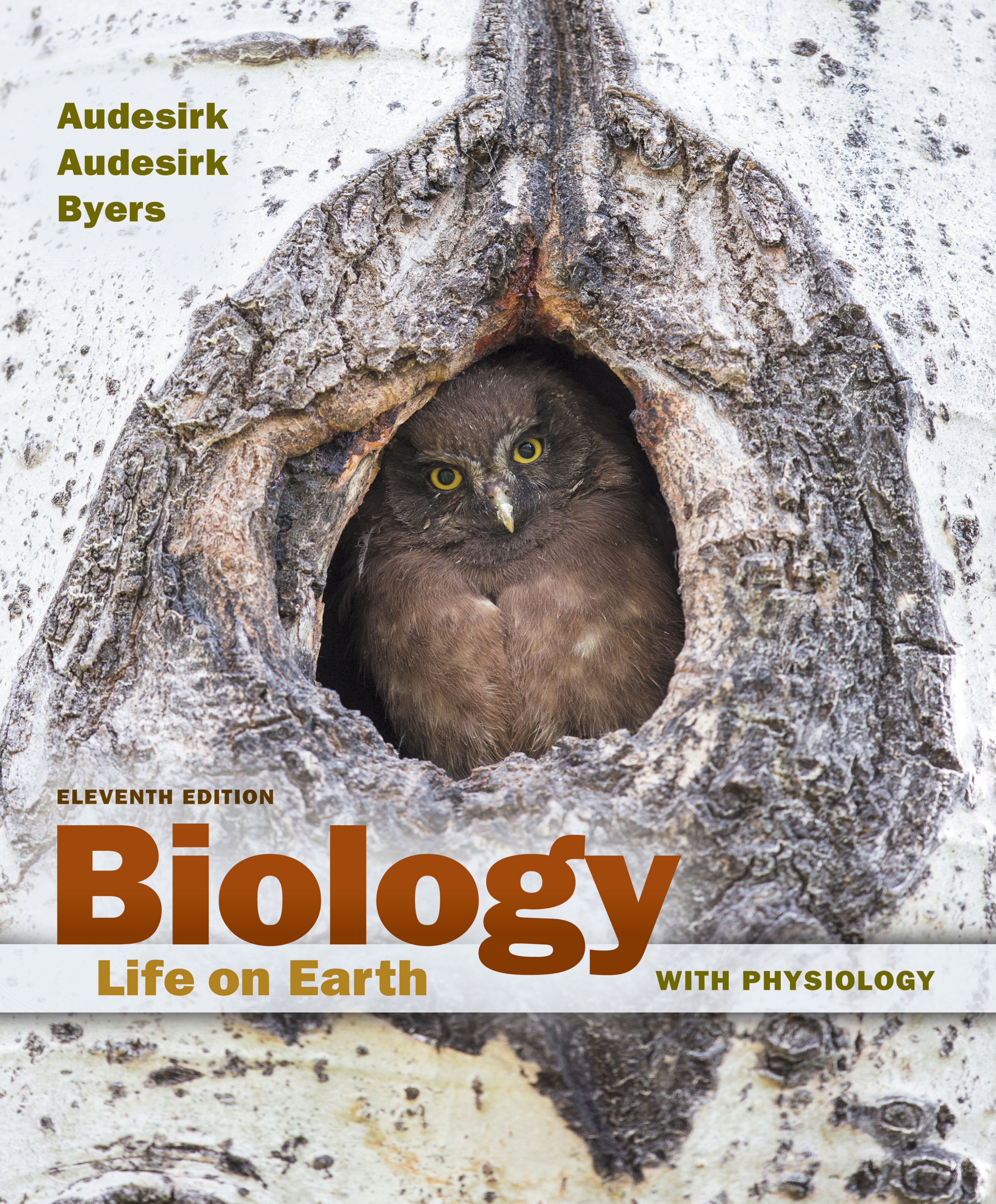

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ELEVENTH EDITION

Biology
Life on Earth
WITH PHYSIOLOGY

BRIEF CONTENTS

CASE STUDIES

ESSAYS

Earth Watch

Health Watch

In Greater Depth

How Do We Know That?

HAVE YOU EVER WONDERED?

ELEVENTH EDITION

BIOLOGY

LIFE ON EARTH WITH PHYSIOLOGY

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ABOUT THE AUTHORS

TERRY AND GERRY AUDESIRK grew up in New Jersey, where they met as undergraduates, Gerry at Rutgers University and Terry at Bucknell University. After marrying in 1970, they moved to California, where Terry earned her doctorate in marine ecology at the University of Southern California and Gerry earned his doctorate in neurobiology at the California Institute of Technology. As postdoctoral students at the University of Washington's marine laboratories, they worked together on the neural bases of behavior, using a marine mollusk as a model system.

They are now emeritus professors of biology at the University of Colorado Denver, where they taught introductory biology and neurobiology from 1982 through 2006. In their research, funded primarily by the National Institutes of Health, they investigated the mechanisms by which neurons are harmed by low levels of environmental pollutants and protected by estrogen.

Terry and Gerry are long-time members of many conservation organizations and share a deep appreciation of nature and of the outdoors. They enjoy hiking in the Rockies, walking and horseback riding near their home outside Steamboat Springs, and singing in the community chorus. Keeping up with the amazing and endless stream of new discoveries in biology provides them with a continuing source of fascination and stimulation. They are delighted that their daughter Heather has become a teacher and is inspiring a new generation of students with her love of chemistry.

BRUCE E. BYERS is a Midwesterner transplanted to the hills of western Massachusetts, where he is a professor in the biology department at the University of Massachusetts Amherst. He has been a member of the faculty at UMass (where he also completed his doctoral degree) since 1993. Bruce teaches courses in evolution, ornithology, and animal behavior, and does research on the function and evolution of bird vocalizations.

With love to Jack, Lori, and Heather and in loving memory of Eve and Joe

— T. A. & G. A.

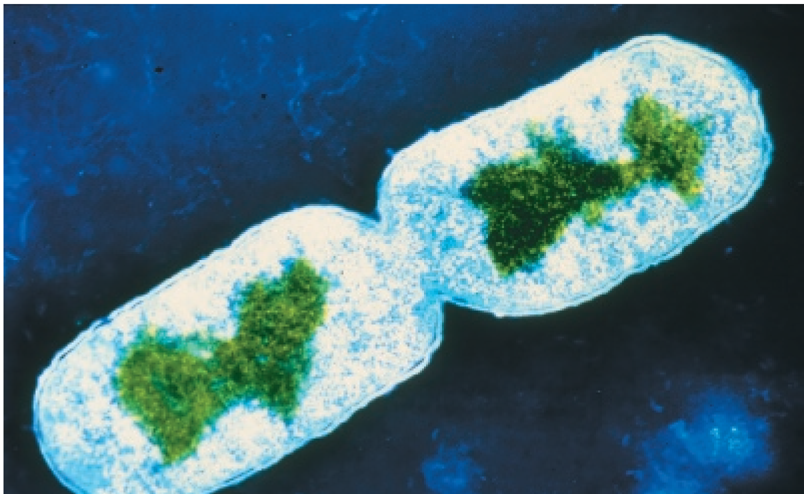
In memory of Bob Byers, a biologist at heart.

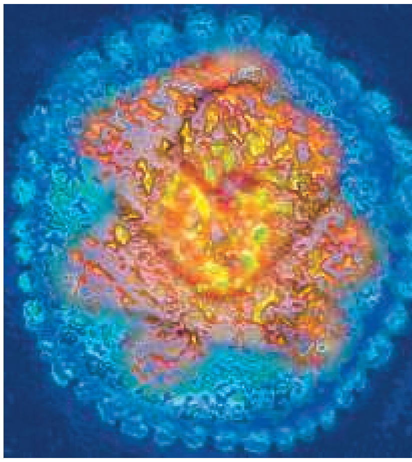
—B. E. B.

ABOUT THE COVER A young boreal owl (*Aegolius funereus*) peers out of a cavity. Boreal owls take their name from the boreal forest, the vast, northern coniferous forest in which they live. The owls inhabit boreal forest in Scandinavia, Siberia, Canada, and Alaska, as well as mountain forests a bit further south. Boreal owls hunt at night, using their keen hearing to find the mice, voles, and other small mammals that make up most of their diet. The owls do not build nests. Instead, a female lays her eggs in a cavity in a tree, often one excavated and abandoned by a woodpecker. About a month later, the eggs hatch. For another month or so, the young owls remain in the cavity, subsisting on food brought by their parents. Eventually, though, a young owl ventures to the mouth of the cavity and prepares to take flight. It will live out its life in a corner of the boreal forest, which is also home to endangered species such as the Amur tiger and the Siberian crane. Unfortunately, the boreal forest biome is threatened by widespread logging and a warming climate.

BRIEF CONTENTS

DETAILED CONTENTS





PREFACE

THE CASE FOR SCIENTIFIC LITERACY

Climate change, biofuels versus food and forests, bioengineering, stem cells in medicine, potential flu pandemics, the plight of polar bears and pandas, human population growth and sustainability: these are just some of the very real, urgent, and interrelated concerns sweeping our increasingly connected human societies. The Internet places a wealth of information—and a flood of misinformation—at our fingertips. Never have scientifically literate students been more important to humanity's future. As educators, we feel humbled before this massive challenge. As authors, we feel hopeful that the Eleventh Edition of *Biology: Life on Earth* will help lead introductory biology students along paths to understanding.

Scientific literacy requires a foundation of factual knowledge that provides a solid and accurate cognitive framework into which new information can be integrated. But more importantly, it endows people with the mental tools to separate the wealth of data from the morass of misinformation. Scientifically literate citizens are better able to evaluate facts and to make informed choices in both their personal lives and the political arena.

This Eleventh Edition of *Biology: Life on Earth* continues our tradition of:

- Helping instructors present biological information in a way that will foster scientific literacy among their students.
- Helping to inspire students with a sense of wonder about the natural world, fostering an attitude of inquiry and a keen appreciation for the knowledge gained through science.
- Helping students to recognize the importance of what they are learning to their future roles in our rapidly-changing world.

WHAT'S NEW IN THIS EDITION?

Each new edition gives the authors a fresh opportunity to ponder: "What can we do better?" With extensive help from reviewers, development editors, and our coauthors, we've answered this question with the following changes organized around three major goals:

Highlight an Inquiry-Driven Approach to Learning

- **Probing questions at the end of the extensively revised "Case Study Continued" segments** help students anticipate what they will learn.
- **Three unique question types in essays and figure captions** encourage students to think critically about the content: "Think Critically" questions focus on solving problems, thinking about scientific data, or evaluating a hypothesis; "Evaluate This" questions ask students to interpret or draw conclusions from a hypothetical scenario; and "Consider This" questions invite students to form an opinion or pose an argument for or against an issue, based on valid scientific information. Answers to "Think Critically" and "Evaluate This" questions are included in the back of the book; hints for "Consider This" questions are included on MasteringBiology.
- **New multiple choice questions at the end of every chapter** address students' recall and comprehension and help them prepare for tests.

Create Connections for Students

- **"Health Watch" essays often include an "Evaluate This" question,** encouraging students to connect health topics to practical, real-world examples.
- **"Threads of Life" themes** in pertinent chapters weave together what may otherwise appear to be unrelated fields within the uniquely diverse science of biology. These threads—identified in our list of changes by chapter below—are the unifying theme of *Evolution*, the exploding science of *Biotechnology*, our increasing recognition of the impacts of *Climate Change*, and our emerging understanding of the importance of *Microbiomes* throughout the living world.
- **Dozens of entirely new and revised figures** illustrate concepts more clearly and engagingly than ever before. For example, negative feedback cycles are now illustrated in a consistent manner that allows students to instantly recognize the chain of events and relate it to negative feedback events in other chapters.

Encourage Critical Thinking

- **New "How Do We Know That?" essays** show students the process of science in a simple way, emphasizing the process and method to what scientists do. Essays go into the details of experiments, highlighting exciting technology and data. "How Do We Know That?" features include "Think Critically" or "Consider This" questions, encouraging students to analyze data or engage with the topics presented in the essay.
- **"Earth Watch" essays include more data.** Students will find more examples of real scientific data in the form of graphs and tables; the data are accompanied by "Think Critically" questions that challenge students to interpret the data, fostering increased understanding of how science is communicated.

In addition, **mitosis and meiosis are now covered in separate chapters** (Chapters 9 and 10, respectively), so students gain a stronger foundational understanding of some of the toughest topics in biology.

BIOLOGY: LIFE ON EARTH, ELEVENTH EDITION

… Is Organized Clearly and Uniformly

Navigational aids help students explore each chapter. An important goal of this organization is to present biology as a hierarchy of closely interrelated concepts rather than as a compendium of independent topics.

- Major sections are introduced as broad questions that stimulate students to think about the material to follow; subheadings are statements that summarize their specific content.
- A "Summary of Key Concepts" section ends each chapter, providing a concise, efficient review of the chapter's major topics.

… Engages and Motivates Students

Scientific literacy cannot be imposed on students—they must actively participate in acquiring the necessary information and skills. To be inspired to accomplish this, they must first recognize that biology is about their own lives. For example, we help students acquire a basic understanding and appreciation of how their own bodies function by including information about diet and weight, cancer, and lower back pain.

We fervently hope that students who use this text will come to see their world through keener eyes. For example, they will perceive forests, fields, and ponds as vibrant and interconnected ecosystems brimming with diverse life-forms rather than as mundane features of their everyday surroundings. If we have done our job, students will also gain the interest, insight, and information they need to look at how humanity has intervened in the natural world. If they ask the question, "Is this activity sustainable?" and then use their new knowledge and critical thinking skills to seek some answers, we can be optimistic about the future.

In support of these goals, the Eleventh Edition has updated features that make Biology more engaging and accessible.

- **Case Studies** Each chapter opens with an attention-grabbing "Case Study" that highlights topics of emerging relevance in today's world. Case Studies, including "Unstable Atoms Unleashed" (Chapter 2), "New Parts for Human Bodies" (Chapter 4), and "Unwelcome Dinner Guests" (Chapter 20), are based on news events, personal interest stories, or particularly fascinating biological topics. "Case Study Continued" segments weave the topic throughout the chapter, whereas "Case Study Revisited" completes the chapter, exploring the topic further in light of the information presented.
- **Boxed Essays** Four categories of essays enliven this text. "Earth Watch" essays explore pressing environmental issues; "Health Watch" essays cover important or intriguing medical topics; "How Do We Know That?" essays explain how scientific knowledge is acquired; and "In Greater Depth" essays make this text versatile for in-depth levels of instruction.
- **"Have You Ever Wondered" Questions** These popular features continue to demystify common and intriguing questions, showing the application of biology in the real world.
- **End-of-Chapter Questions** The questions that conclude each chapter allow students to review the material in different formats—multiple choice, fill-in-the-blank, and essay—that help them to study and test what they have learned. Answers to the multiple choice and fill-in-the-blank questions are included in the back of the book. Answers or hints for the essay questions are included on MasteringBiology.
- **Key Terms and a Complete Glossary** Boldfaced key terms are defined clearly within the text as they are introduced. These terms are also listed at the end of each chapter, providing users with a quick reference to the chapter's important vocabulary. The glossary, carefully written by the authors, provides exceptionally complete definitions for all key terms, as well as for many other important biological terms.

… Is a Comprehensive Learning Package

The Eleventh Edition of *Biology: Life on Earth* is a complete learning package, providing updated and innovative teaching aids for instructors and learning aids for students.

CHAPTER-BY-CHAPTER SUMMARY OF IMPORTANT CHANGES

Following the revision of chapters in response to reviews by instructors and experts, the text and artwork were carefully reviewed by each of the other two authors and the development editors. The coauthors provided valuable insights to one another, integrating the chapters more thoroughly, improving consistency between chapters, and explaining complex concepts more clearly. Our development editors brought trained eyes for order and detail to our work, helping us make the writing even more student-friendly. Following this intense scrutiny, each initial revision underwent a second, sometimes extensive revision. Specific changes include the following:

- **Chapter 1: An Introduction to Life on Earth** includes an entirely updated Case Study to reflect the recent Ebola epidemic. A new "Have You Ever Wondered: Why Scientists Study Obscure Organisms?" highlights unforeseen benefits that have emerged from investigating different organisms. Our *Evolution* "Thread of Life" is emphasized throughout and *Climate Change* is noted in the context of evolution.

UNIT 1 The Life of the Cell

- **Chapter 2: Atoms, Molecules, and Life** offers improved coverage of the unique properties of water. The essay "How Do We Know That? Radioactive Revelations" includes new PET images. The essay "Health Watch: Free Radicals—Friends and Foes?" incorporates new findings on antioxidant supplements. Figures 2-1, 2-2, 2-3, 2-4, 2-5, and 2-6 have been revised for greater clarity and consistency.
- **Chapter 3: Biological Molecules** now covers lipids last, because they are distinct in their structural diversity and in not forming polymers. The discussion of protein structure and intrinsically disordered proteins has been extensively revised. The "Health Watch" essay on trans fats and cholesterol has been extensively updated and rewritten, as has the "Have You Ever Wondered" essay on hair structure. Figures 3-1 and 3-3 and Table 3-2 have undergone major revisions.
- **Chapter 4: Cell Structure and Function** features an entirely new Case Study supporting our *Biotechnology* thread. There is new art for relative sizes as well as enhanced coverage and new art of the extracellular matrix and cytoskeleton (Figures 4-1, 4-6, and 4-7, respectively). Prokaryotic cells are now covered before eukaryotic cells. A new "Earth Watch" essay discusses the environmental impact of raising livestock and the culturing of cow muscle in the lab. "Have You Ever Wondered" has been revised and introduces our *Microbiome* thread.
- **Chapter 5: Cell Membrane Structure and Function** includes upgraded figures of the plasma membrane (Figure 5-1), phospholipids (Figure 5-2), membrane receptors (Figure 5-3), osmosis (Figure 5-6), and surface/volume relationship (Figure 5-13). Added micrographs illustrate cell junctions (Figure 5-14). The "How Do We Know That?" essay on aquaporins has been updated and now includes a data figure. Membrane fluidity has now been incorporated into a "Health Watch" essay, and there is a new "Have You Ever Wondered" essay describing how antibiotics destroy bacteria and supporting our *Evolution* thread.
- **Chapter 6: Energy Flow in the Life of a Cell** includes an updated Case Study, as well as revised art of coupled reactions (Figure 6-7), feedback inhibition (Figure 6-12), and regenerative braking (Figure E6-1). There are new images for entropy (Figure 6-3), activation energy (Figure 6-5b), and food preservation (Figure 6-14). Our explanation of the second law of thermodynamics now uses the phrase "isolated system." The section on solar energy incorporates the *Climate Change* thread. The revised "Health Watch" essay on lactose intolerance supports our *Evolution* thread and a revised "Have You Ever Wondered" about glowing plants supports our *Biotechnology* thread.
- **Chapter 7: Capturing Solar Energy: Photosynthesis** has a revised and updated Case Study, a new overview figure (Figure 7-1), and a chloroplast micrograph added to the figure illustrating photosynthetic structures (Figure 7-3). Figures describing energy transfer in the light reactions (Figure 7-7) and the C_4 and CAM pathways (Figures E7-1 and E7-2) have been significantly improved. The section The Calvin Cycle Captures Carbon Dioxide incorporates the *Biotechnology* thread. The "Earth Watch" essay on biofuels has been updated and supports our *Climate Change* thread.
- **Chapter 8: Harvesting Energy: Glycolysis and Cellular Respiration** features an entirely new Case Study on on the use of mitochondrial DNA in the identification of King Richard III of England. The essay "Health Watch: How Can You Get Fat by Eating Sugar?" has new art showing the conversion of sugar to fat. A micrograph of the mitochondrion has been added to Figure 8-4; the electron transport chain in Figure 8-6 has been redrawn; a new Figure 8-8 illustrates energy extraction from foods; and a new Table 8-1 summarizes glucose breakdown.

UNIT 2 Inheritance

- **Chapter 9: Cellular Reproduction** now covers only mitotic cell division and the control of the cell cycle; meiotic cell division and its importance in sexual reproduction are discussed in Chapter 10. Chapter 9 opens with a new Case Study describing the potential of stem cell therapy for healing injuries. Figure 9-2 illustrates the two important properties of stem cells: self-renewal and the ability of their daughter cells to differentiate into multiple cell types. Cloning is briefly introduced as a technology-based form of asexual reproduction, continuing the *Evolution* thread.
- **Chapter 10: Meiosis: The Basis of Sexual Reproduction** begins with a new Case Study, which illustrates how the genetic variability produced by meiosis can be strikingly visible in everyday life. Descriptions of disorders such as Down syndrome and Turner syndrome have been moved into this chapter. A new "How Do We Know That?" essay describes hypotheses and experiments that explore selective forces that may favor the evolution of sexual reproduction, continuing the *Evolution* thread.
- **Chapter 11: Patterns of Inheritance** now includes photos in Figure 11-21, showing how the world looks to color-deficient people—highly accurate images, as verified by the color-deficient author. The "Have You Ever Wondered" essay on the inheritance of body size in dogs includes new information.
- **Chapter 12: DNA: The Molecule of Heredity** now features a streamlined description of the seminal Hershey-Chase experiment in "How Do We Know That? DNA Is the Hereditary Molecule."

- **Chapter 13: Gene Expression and Regulation** contains a revised and updated "Health Watch" essay on epigenetic control of gene expression.
- **Chapter 14: Biotechnology** begins with a new Case Study. The entire chapter has been updated with current information, including recently developed methods for using single-nucleotide polymorphisms to provide information on physical characteristics of both living and ancient humans; possible applications of biotechnology in environmental bioengineering; and using DNA microarrays to diagnose both inherited disorders and infectious diseases. The "How Do We Know That?" essay on prenatal genetic screening asks the students to use their knowledge of forensic DNA and prenatal testing in a simulated paternity case.

UNIT 3 Evolution and Diversity of Life

- **Chapter 15: Principles of Evolution** includes a largely new "How Do We Know That?" essay describing some of the evidence that led Darwin to formulate his theory. The section on evidence of natural selection in the wild includes a new example. "Earth Watch: People Promote High-Speed Evolution" supports our *Climate Change* thread.
- **Chapter 16: How Populations Evolve** includes a revised explanation of how population size affects genetic drift, with a new accompanying figure (Figure 16-5). The "In Greater Depth" essay includes a new figure to aid visualization of the Hardy–Weinberg principle. The section on mutation has been updated to reflect the latest research on mutation rates. A new "Health Watch" essay describes a Darwinian approach to thinking about cancer.
- **Chapter 17: The Origin of Species** presents a new Case Study about the discovery of new species. New, data-based graphics have been added to "Eart h Watch: Why Preserve Biodiversity?" and "How Do We Know That? Seeking the Secrets of the Sea."
- **Chapter 18: The History of Life** includes a new Case Study about how our newfound ability to recover and sequence ancient (fossil) DNA provides insight into evolutionary history. We include updated information on fossils found since the previous edition. All dates have been updated to reflect the latest Geological Society revisions of the geological time scale. The human evolution section now contains information about *Homo floresiensis*. There is a new photo of a protist with an algal endosymbiont (Figure 18-6); new photos of early hominin tools (Figure 18-15); and a new artist's conception of a Carboniferous landscape (Figure 18-8).
- **Chapter 19: Systematics: Seeking Order Amid Diversity** includes a new "Have You Ever Wondered" essay about using systematics to estimate how long ago humans began to wear clothing. The account of current views on taxonomic ranks has been streamlined. Text and figures in "In Greater Depth: Phylogenetic Trees" have been revised for increased clarity.
- **Chapter 20: The Diversity of Prokaryotes and Viruses** presents a revised section on prokaryotic systematics that now includes descriptions of some specific clades. A new Table 20-1 summarizes the differences between Archaea and Bacteria. The chapter includes new descriptions of photosynthetic and subterranean bacteria. "Health Watch: Is Your Body's Ecosystem Healthy?" supports our *Microbiome* thread.
- **Chapter 21: The Diversity of Protists** includes a new "Health Watch" essay about diseases caused by protists. The sections on brown algae and red algae now include information on foods derived from those organisms. The description of chlorophytes has been revised to reflect improved understanding of the group's phylogeny, and the section also supports our *Biotechnology* thread. The chapter contains new photos of a parabasalid (Figure 21-3), a dinoflagellate (Figure 21-8), and chlorophytes (Figure 21-19).
- **Chapter 22: The Diversity of Plants** includes a new essay, "Health Watch: Green Lifesaver," about an important antimalarial derived from a plant, highlighting our *Biotechnology* thread. A new figure (Figure 22-3) illustrates some key adaptations for life on land.
- **Chapter 23: The Diversity of Fungi** contains a new essay, "Earth Watch: Killer in the Caves," which describes a fungal disease that threatens bat populations. The chapter contains new information on an airborne fungal disease of humans, the dangers of toxic mushrooms, and fungi known only from DNA sequences. A new segment on genetically engineered resistance to chestnut blight supports our *Biotechnology* thread.
- **Chapter 24: Animal Diversity I: Invertebrates** includes a new "Earth Watch" essay about coral reef bleaching. "How Do We Know That? The Search for a Sea Monster" focuses on the most recent expedition to search for giant squids. All species counts are updated to reflect the latest numbers from the Catalogue of Life.
- **Chapter 25: Animal Diversity II: Vertebrates** contains a new "Have You Ever Wondered" about shark attacks. The chapter contains new information about hagfish slime and new information about snake digestive physiology. "Earth Watch: Frogs in Peril" has been updated with new information and a new graph. All species counts are updated to reflect the latest numbers from the Catalogue of Life.

UNIT 4 Behavior and Ecology

- **Chapter 26: Animal Behavior** has been extensively revised and updated, including new material and many new figures.
- **Chapter 27: Population Growth and Regulation** opens with a new Case Study on the crash and subsequent regrowth of populations of northern elephant seals. Figure 27-1, illustrating exponential growth, has been revised. Section 27.3 offers a new discussion of life history strategies and their evolution, which also supports our *Evolution* thread. The chapter has been updated with current statistics and figures related to the growth of the human population.
- **Chapter 28: Community Interactions** begins with a new Case Study about endangered Channel Island foxes. Section 28.1 has been expanded to describe the different types of community interactions. Section 28.3 has been extensively revised to describe consumer–prey interactions as a general category that includes all situations in which one organism (the consumer) feeds on another (the prey), and encompasses predation (including herbivory) and parasitism. A new "Have You Ever Wondered" essay explains why rattlesnakes rattle. A new "Health Watch" essay explores how coevolution between parasites and their hosts can produce a range of outcomes, supporting our *Microbiome* thread.
- **Chapter 29: Energy Flow and Nutrient Cycling in Ecosystems** includes updated information on atmospheric carbon dioxide and supports our *Climate Change* thread. A new "How Do We Know That?" essay explores the ways in which scientists monitor Earth's conditions. The "Health Watch" essay on biological magnification includes a new figure.
- **Chapter 30: Earth's Diverse Ecosystems** provides a clear explanation of why global average temperature decreases with latitude, including a new illustration in Figure 30-2a. Descriptions of monsoons and the El Nino/Southern Oscillation have been added to Section 30.2.
- **Chapter 31: Conserving Earth's Biodiversity** opens with a new Case Study of the effects of extirpating, and then reintroducing, wolves in Yellowstone National Park. The description of ecosystem services is now organized into the four categories used by the *Millennium Ecosystem Assessment* and The Economics of Ecosystems and Biodiversity (TEEB). There are new images of rain-forest destruction (Figure 31-4) and wildlife corridors (Figure 31-8).

UNIT 5 Animal Anatomy And Physiology

- **Chapter 32: Homeostasis and the Organization of the Animal Body** includes a major revision of the Case Study on hyperthermia, including a Consider This question supporting our *Climate Change* thread. Figures illustrating negative feedback (Figure 32-2) and the cell to organ hierarchy (Figure 32-3) have undergone major revisions, and micrographs were added to epithelial cell types (Figure 32-4). A revised "Earth Watch" essay better emphasizes the positive feedback effects of *Climate Change* in the Arctic.
- **Chapter 33: Circulation** opens with an entirely rewritten Case Study about human heart transplants and introduces the *Biotechnology* thread in the Case Study Revisited. Figure 33-3 now shows the human heart within the chest cavity. Figure 33-10, showing red blood cell regulation, has been redrawn.
- **Chapter 34: Respiration** begins with an all new Case Study about athletic training at high altitude, which includes "Continued" sections on respiratory disorders. A new "Have You Ever Wondered" discusses shark swimming and respiration, supported by the rewritten "In Greater Depth: Gills and Gases" covering countercurrent exchange. Our *Evolution* thread is supported by our discussion of two-, three-, and four-chambered vertebrate hearts.
- **Chapter 35: Nutrition and Digestion** includes a new figure to illustrate calorie expenditures in relation to activity and food intake (Figure 35-1), updated USDA recommendations compared with actual diets (Figure 35-6), an illustration of proposed changes in food nutritional information labels (Figure 35-7), and a new figure of peristalsis (Figure 35-16). Micrographs have been added to the small intestine structures (Figure 35-19), and a new figure illustrates negative feedback of leptin on body fat (Figure 35-20). A discussion of bacterial communities in both cow and human digestive tracts highlights our *Microbiome* thread.
- **Chapter 36: The Urinary System** has an extensively rewritten section on the comparative physiology of nitrogenous waste excretion, including a new table (Table 36-1). The terms renal corpuscle, renal capsule, nephron loop, absorption, and secretion are introduced. New illustrations of human nephron structure and function (Figures 36-4 and 36-5) improve clarity, and the negative feedback cycle involving ADH release and water retention has been redrawn (Figure 36-6). The chapter features an updated Case Study and "Health Watch" essay, both of which incorporate our *Biotechnology* thread.
- **Chapter 37: Defenses Against Disease** includes a description of the Ebola virus in "Health Watch: Deadly Emerging Viruses." The essay "How Do We Know That? Vaccines Can Prevent Infectious Diseases" discusses the benefits of vaccination and asks students to evaluate a graph.
- **Chapter 38: Chemical Control of the Animal Body: The Endocrine System** begins with a new Case Study on Type 2 diabetes. Figure 38-9 has been completely reworked to more clearly illustrate the

interplay between glucagon and insulin in the control of blood glucose. The "Health Watch" essay focuses on commonly abused types of PEDs.

- **Chapter 39: The Nervous System** includes micrographs of neurons and synapses (Figures 39-1 and 39-4, respectively). Figure 39-10 has been revised. We discuss brain lateralization in non-human vertebrates, a fairly constant feature throughout vertebrate *Evolution*. The "Health Watch" essay on addiction now shows PET scans. The "How Do We Know That?" essay on neuroimaging includes exciting new experiments showing that brain activity can be used to reconstruct and recognize specific faces—and informs the students that an undergraduate had the idea for the research.
- **Chapter 40: The Senses** includes a new Section 40.2 on thermoreception. Micrographs have been added to figures showing the structures of the ear (Figure 40-4), retina (Figure 40-7), olfactory epithelium (Figure 40-11), and taste buds (Figure 40-12). A new "Earth Watch" essay describes how noise pollution in the ocean may be impairing communication among whales and incorporates our *Evolution* thread. A new critical thinking question in the "Case Study Revisited" introduces our *Biotechnology* thread.
- **Chapter 41: Action and Support: The Muscles and Skeleton** begins with a substantially rewritten Case Study. Sections 41.1 and 41.2 have been significantly revised. A new "Have You Ever Wondered" compares white and dark meat. A new figure (Figure 41-16) provides data comparing fiber proportions in average people, marathoners, and sprinters; many other figures have been substantially revised.
- **Chapter 42: Animal Reproduction** includes updated information about sexually transmitted diseases, contraception, and in vitro fertilization, including a description of the technology to produce "three-parent" babies, supporting the *Bioengineering* thread. Micrographs of seminiferous tubules and corpus luteum have been added to Figures 42-10 and 42-16, respectively. Figure 42-13, the hormonal control of testosterone secretion and spermatogenesis, has been extensively revised.
- **Chapter 43: Animal Development** now discusses hypotheses that attempt to explain the selective advantages of different forms of aging. "Have You Ever Wondered: Why Childbirth Is So Difficult?" includes a new diagram and new hypotheses and data, supporting our *Evolution* thread.

UNIT 6 Plant Anatomy and Physiology

- **Chapter 44 Plant Anatomy and Nutrient Transport** includes a major revision of the ground and epidermal tissue systems and introduces the terms *trichomes* and *indeterminate growth*. The section describing root structure and function has been revised. New photos illustrate ground tissue (Figure 44-4) and root nodules (Figure 44-22).
- **Chapter 45 Plant Reproduction and Development** has an updated Case Study describing corpse flower seeds and their dispersers. Revised figures better illustrate seed development (Figure 45-12) and germination (Figure 45-13). A new "How Do We Know That? Tastier Fruits and Veggies are Coming!" explains the new science of marker-assisted selection and supports our *Biotechnology* thread.
- **Chapter 46 Plant Responses to the Environment** includes a new photo showing the effects of gibberellin (Figure 46-1), an extensively revised section on auxin and seed sprouting, and a major revision of Figure 46-3 illustrating the role of auxin in gravitropism. Art illustrating the interconversion of phytochromes now accompanies Table 46-2 describing this phenomenon.

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We are extremely fortunate to be working with the Pearson team. This Eleventh Edition of *Biology: Life on Earth* reflects their exceptional abilities and dedication.

With gratitude,

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Hallmark Case Studies place biology in a real-world context

A **Case Study** describing a true and relevant event or phenomenon runs throughout each chapter, tying biological concepts to the real world.

10 MEIOSIS: THE BASIS OF SEXUAL REPRODUCTION

The Giddings family is a rainbow of colors.

CASE STUDY

The Rainbow Connection

FIRST CAME JACOB, WHO HAS BLUE EYES like his mom, Tess, but curly brown hair and olive skin. Next came Savannah, who looks a lot like Jacob, though her hair is perhaps more dark blond than brown. Amiah, however, was truly a surprise when she was born—she has very pale skin, with straight, sandy-brown hair. Zion, the youngest child, has dark skin, black curly hair, and brown eyes, similar to his father, Chris. Even in today's multicultural England, a family like that is unusual.

Tess and Chris Giddings are as surprised as everyone else by their rainbow family. In fact, when Amiah was born, she had low blood sugar and needed to be checked out by a specialist right away. She was whisked away so fast that the hospital staff hadn't put an ID wristband on her yet. When she was returned to her parents a little while later, they were astounded at how white her skin was. They asked the inevitable question: Was she switched with another baby by mistake? Just to be sure, the Giddings agreed to a DNA test. The results showed that Tess and Chris were indeed Amiah's parents. When Zion was born a few years later, Chris burst out, "Oh my God, he's black!" To which the astounded midwife could only reply, "You do know you're a black man, don't you?"

How could one couple have such a diverse family? As we will see in this chapter, sexual reproduction can mix inherited characteristics from the parents into a remarkable variety of different offspring. How does sexual reproduction produce genetic diversity? And why would natural selection favor seemingly random shuffling of traits?

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All chapters open with a **Case Study,** a true yet extraordinary story that relates to the science presented in the chapter. The **Eleventh Edition** explores several **new** Case Study topics including the Ebola epidemic (Chapter 1), DNA Identification (Chapter 8), and Biotechnology (Chapter 14).

NEW! Chapter 9 now covers only mitotic cell division and the control of the cell cycle. Meiotic cell division and its importance in sexual reproduction are discussed in Chapter 10.

CASE STUDY CONTINUED

The Rainbow Connection

The genetic variability of the Giddings children started out as mutations that occurred thousands of years ago. Take hair color: Our distant ancestors probably all had dark hair, its color controlled by multiple genes located on several different chromosomes. The alleles that produced Tess's blond hair originated as mutations in genes that control the amount and type of hair pigment. Tess probably inherited only "pale hair" alleles of all of these genes, so for any given hair color gene, she has the same pale hair allele on both homologous chromosomes. Chris, on the other hand, inherited both dark and pale hair alleles for at least some of the genes, so his homologues have different alleles. As we will see in Chapter 11, in many cases one allele (in this case, the dark hair allele) overrides the effects of the other allele (the pale hair allele), so Chris has black hair. What combinations of alleles might have been packaged in Tess's eggs and Chris's sperm, which would combine to produce their diverse children?

Every chapter contains **Case Study Continued** sections that appear when you are well into the chapter. These sections expand on the **Chapter Opening Case Studies** and connect to biological concepts you will have learned.

CASE STUDY REVISITED

The Rainbow Connection

Many people are astounded by the diversity of the Giddings children. Basic biology, however, easily explains how such diversity arises. Most genes have multiple alleles, meiotic cell division separates homologous chromosomes—and the alleles they carry—into different sperm and eggs, and the sperm and eggs unite at random. From a biological perspective, perhaps the more interesting question is this: Why do alleles for dark pigmentation occur most frequently in people whose ancestors lived in equatorial regions, and alleles for pale pigmentation in people of northern European ancestry?

Natural selection probably favored different skin colors because of the differing amount of sunlight in equatorial versus northern regions and the importance of vitamin D and vitamin B_9 (folate) in human health. Vitamin D is needed for many physiological functions, including the absorption of calcium and other minerals by the digestive tract. Folate is also essential for many bodily functions. Folate deficiency can cause anemia and other disorders in adults and serious nervous system abnormalities in developing fetuses.

Ultraviolet rays in sunlight stimulate the synthesis of vitamin D, but they break down folate. In the fierce sunlight of equatorial regions, dark skin still allows for plenty of vitamin D production, while protecting against too much depletion of folate. In northern Europe, with far weaker sunlight and often cloudy skies, paler skin boosts vitamin D production, while folate levels remain adequate.

The selective advantage of blond hair in northern Europe is more uncertain. Some of the same genes contribute to hair and skin color, so selection for pale skin may have selected for pale hair as well. Another hypothesis is that the first few people with blond hair were very conspicuous in a population of otherwise dark-haired people. Novel appearance, within limits, is often attractive to members of the opposite sex. Some anthropologists have speculated that, a few thousand years ago, high-status men (proficient hunters or chieftains of small tribes, for example) preferentially chose blond-haired women as mates. Therefore, blond women produced more offspring than dark-haired women did. The result is that more than half the people in parts of Scandinavia have blond hair.

CONSIDER THIS Ultraviolet rays in sunlight cause skin cancer. In today's world, people of all skin colors, but especially pale-skinned people, are often urged to stay out of the sun and get their vitamin D from food or supplements. In the past, do you think that the risk of skin cancer selected against pale-skinned people, partially counterbalancing selection in favor of pale skin for vitamin D production?

A **Case Study Revisited** section wraps up the narrative of each chapter by connecting the biological themes described throughout the chapter with the everyday science brought out in the Case Study. The accompanying **Consider This** question allows further reflection on how the biology in the Case Study can be applied to a new situation.

NEW! Three-pronged taxonomy of questions in each chapter

Each chapter is organized around a consistent framework of questions that encourage students to look forward, look back, or dig deeper.

AT A GLANCE

CASE STUDY

Guilty or Innocent?

IMAGINE SPENDING WELL OVER
for crimes you didn't commit. For
real life for Thomas Haynesworth

The section **headings** and **case study** sections give a preview of questions that will be addressed in the chapter.

CHECK YOUR LEARNING

Can you …

- explain why people might be opposed to the use of genetically modified organisms in agriculture?
- envision circumstances in which it would be ethical to modify the genome of a human fertilized egg?

The **Check Your Learning** and **End of Chapter questions** ask students to look back, recall, and reinforce their comprehension of biology concepts.

Thinking Through the Concepts

Multiple Choice

1. Which of the following is *not* true of a single nucleotide polymorphism?
   a. It is usually caused by a translocation mutation.
   b. It is usually caused by a nucleotide substitution mutation.
   c. It may change the phenotype of an organism.
   d. It is inherited from parent to offspring.
2. Imagine you are looking at a DNA profile that shows an STR pattern of a mother's DNA and her child's DNA. Will all of the bands of the child's DNA match those of the mother?
   a. Yes, because the mother's DNA and her child's DNA are identical.
   b. Yes, because the child developed from her mother's egg.
   c. No, because half of the child's DNA is inherited from its father.
   d. No, because the child's DNA is a random sampling of its mother's.
3. Which of the following is *not* a commonly used method of modifying the DNA of an organism?
   a. crossbreeding two plants of the same species
   b. crossbreeding two plants of different species
   c. the polymerase chain reaction
   d. genetic engineering
4. A restriction enzyme
   a. cuts DNA at a specific nucleotide sequence.
   b. cuts DNA at a random nucleotide sequence.
   c. splices pieces of DNA together at a specific nucleotide sequence.
   d. splices pieces of DNA together without regard to the nucleotide sequence.
5. DNA cloning is
   a. making multiple genetically identical cells.
   b. making multiple copies of a piece of DNA.
   c. inserting DNA into a cell.
   d. changing the nucleotide sequence of a strand of DNA.

CONSIDER THIS Genetic engineering is used both in food crops and in medicine. Golden Rice and almost all the corn and soybeans grown in the United States contain genes from other species. The he
by inserting a gene from th
The antibodies in ZMapp, c
Ebola therapy, are part mo
scientifically important diff
engineering for food or for

EVALUATE THIS In January 2012, the Pittsburgh Steelers football team played against the Denver Broncos in the "Mile-High City" (Denver's altitude is a mile above sea level). Steelers head coach Mike Tomlin did not allow safety Ryan Clark to play, because Clark has sickle-cell trait. What can happen when someone with sickle-cell trait exercises at high
e right call in bench-

Applying the Concepts

1. As you may know, many insects have evolved resistance to common pesticides. Do you think that insects might evolve resistance to *Bt* crops? If this is a risk, do you think that *Bt* crops should be planted anyway? Why or why not?
2. All children born with X-linked SCID are boys. Can you e

THINK CRITICALLY There are many other applications in which DNA barcoding might be useful. For example, how might ecologists use DNA barcoding to find out what species are present in a rain forest, or what kinds of animals a predator eats?

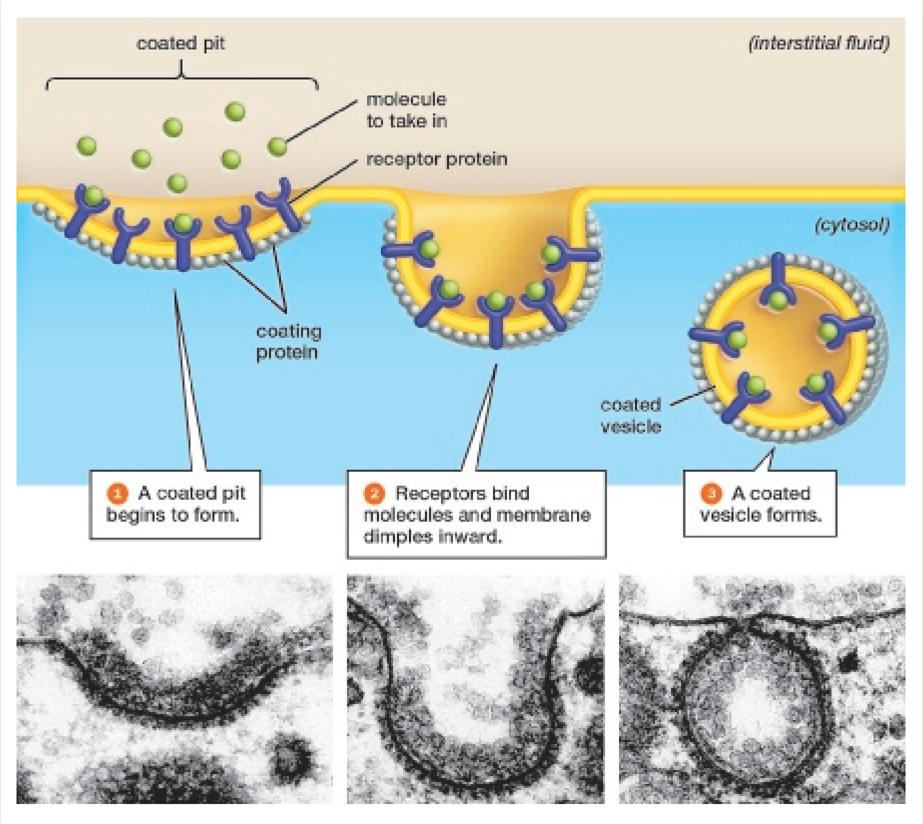
Consider This, **Think Critically**, **Evaluate This** and **Applying the Concepts** ask students to dig deeper, reflect, and think critically about the chapter material.

NEW! Think Critically questions challenge readers to apply their knowledge to information presented in a photo, figure, graph, or table.

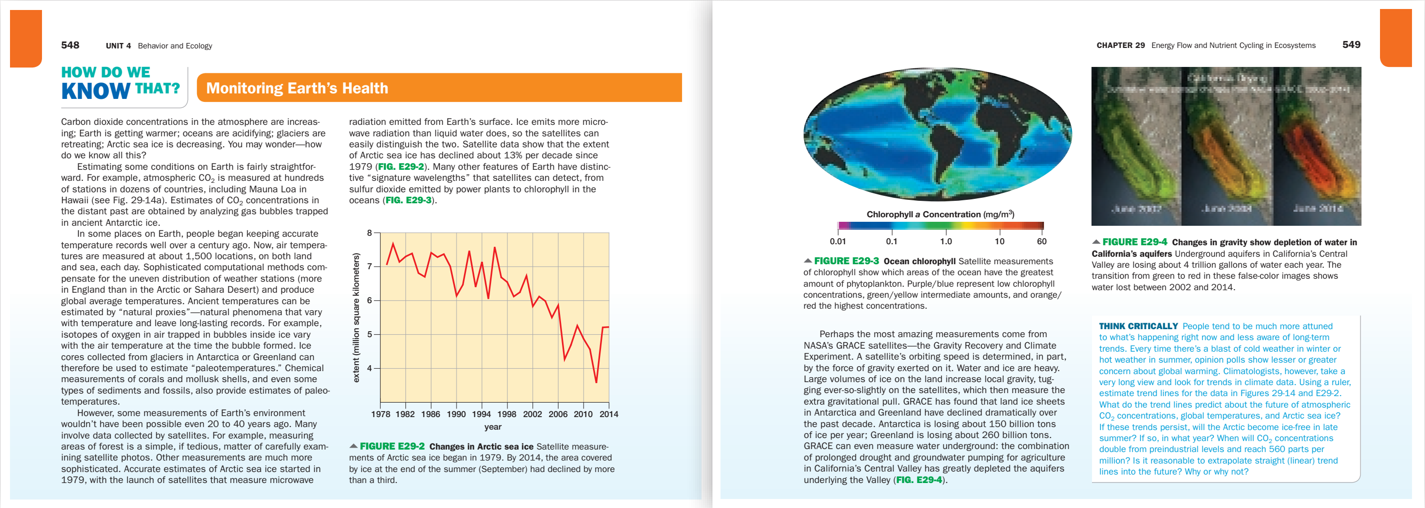
NEW! Evaluate This questions present a brief, realistic health care scenario and ask the reader to evaluate information before forming an opinion or making a decision.

NEW! Revised Art and Content Throughout

Improved Figures and Photos appear throughout the text and include easy-to-follow process diagrams with labeled steps and a clearer use of color for distinguishing different structures.



NEW! How Do We Know That? Essays explore the process of scientific discovery, experimental design, and exciting new biotechnology techniques, explaining how scientists know what they know about biology.



548 UNIT 4 Behavior and Ecology

HOW DO WE KNOW THAT? **Monitoring Earth's Health**

Carbon dioxide concentrations in the atmosphere are increasing; Earth is getting warmer; oceans are acidifying; glaciers are retreating; Arctic sea ice is decreasing. You may wonder—how do we know all this?

Estimating some conditions on Earth is fairly straightforward. For example, atmospheric CO_2 is measured at hundreds of stations in dozens of countries, including Mauna Loa in Hawaii (see Fig. 29-14a). Estimates of CO_2 concentrations in the distant past are obtained by analyzing gas bubbles trapped in ancient Antarctic ice.

In some places on Earth, people began keeping accurate temperature records well over a century ago. Now, air temperatures are measured at about 1,500 locations, on both land and sea, each day. Sophisticated computational methods compensate for the uneven distribution of weather stations (more in England than in the Arctic or Sahara Desert) and produce global average temperatures. Ancient temperatures can be estimated by "natural proxies"—natural phenomena that vary with temperature and leave long-lasting records. For example, isotopes of oxygen in air trapped in bubbles inside ice vary with the air temperature at the time the bubble formed. Ice cores collected from glaciers in Antarctica or Greenland can therefore be used to estimate "paleotemperatures." Chemical measurements of corals and mollusk shells, and even some types of sediments and fossils, also provide estimates of paleotemperatures.

However, some measurements of Earth's environment wouldn't have been possible even 20 to 40 years ago. Many involve data collected by satellites. For example, measuring areas of forest is a simple, if tedious, matter of carefully examining satellite photos. Other measurements are much more sophisticated. Accurate estimates of Arctic sea ice started in 1979, with the launch of satellites that measure microwave radiation emitted from Earth's surface. Ice emits more microwave radiation than liquid water does, so the satellites can easily distinguish the two. Satellite data show that the extent of Arctic sea ice has declined about 13% per decade since 1979 (**FIG. E29-2**). Many other features of Earth have distinctive "signature wavelengths" that satellites can detect, from sulfur dioxide emitted by power plants to chlorophyll in the oceans (**FIG. E29-3**).

extent (million square kilometers): 8, 7, 6, 5, 4
year: 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014

▲ **FIGURE E29-2 Changes in Arctic sea ice** Satellite measurements of Arctic sea ice began in 1979. By 2014, the area covered by ice at the end of the summer (September) had declined by more than a third.

CHAPTER 29 Energy Flow and Nutrient Cycling in Ecosystems 549

Chlorophyll *a* Concentration (mg/m^3): 0.01, 0.1, 1.0, 10, 60

▲ **FIGURE E29-3 Ocean chlorophyll** Satellite measurements of chlorophyll show which areas of the ocean have the greatest amount of phytoplankton. Purple/blue represent low chlorophyll concentrations, green/yellow intermediate amounts, and orange/red the highest concentrations.

Perhaps the most amazing measurements come from NASA's GRACE satellites—the Gravity Recovery and Climate Experiment. A satellite's orbiting speed is determined, in part, by the force of gravity exerted on it. Water and ice are heavy. Large volumes of ice on the land increase local gravity, tugging ever-so-slightly on the satellites, which then measure the extra gravitational pull. GRACE has found that land ice sheets in Antarctica and Greenland have declined dramatically over the past decade. Antarctica is losing about 150 billion tons of ice per year; Greenland is losing about 260 billion tons. GRACE can even measure water underground: the combination of prolonged drought and groundwater pumping for agriculture in California's Central Valley has greatly depleted the aquifers underlying the Valley (**FIG. E29-4**).

▲ **FIGURE E29-4 Changes in gravity show depletion of water in California's aquifers** Underground aquifers in California's Central Valley are losing about 4 trillion gallons of water each year. The transition from green to red in these false-color images shows water lost between 2002 and 2014.

THINK CRITICALLY People tend to be much more attuned to what's happening right now and less aware of long-term trends. Every time there's a blast of cold weather in winter or hot weather in summer, opinion polls show lesser or greater concern about global warming. Climatologists, however, take a very long view and look for trends in climate data. Using a ruler, estimate trend lines for the data in Figures 29-14 and E29-2. What do the trend lines predict about the future of atmospheric CO_2 concentrations, global temperatures, and Arctic sea ice? If these trends persist, will the Arctic become ice-free in late summer? If so, in what year? When will CO_2 concentrations double from preindustrial levels and reach 560 parts per million? Is it reasonable to extrapolate straight (linear) trend lines into the future? Why or why not?

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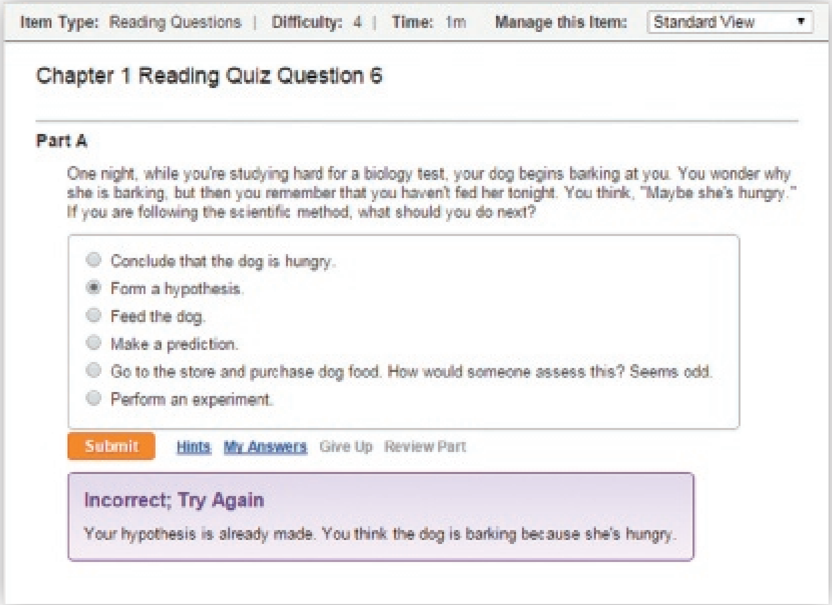
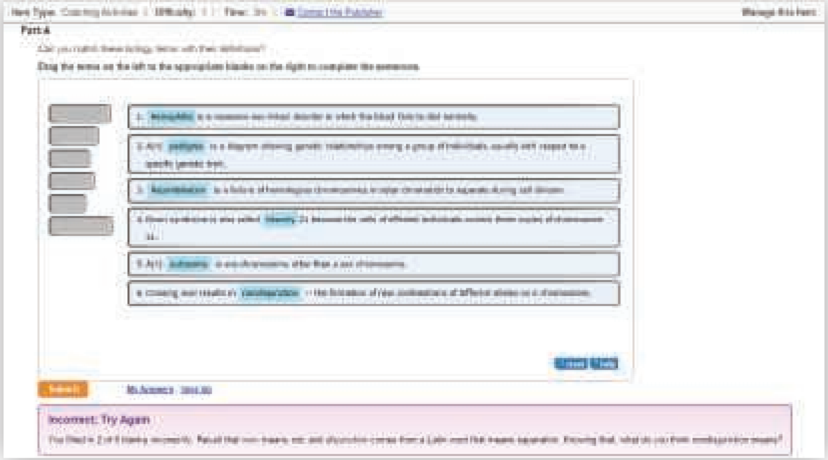
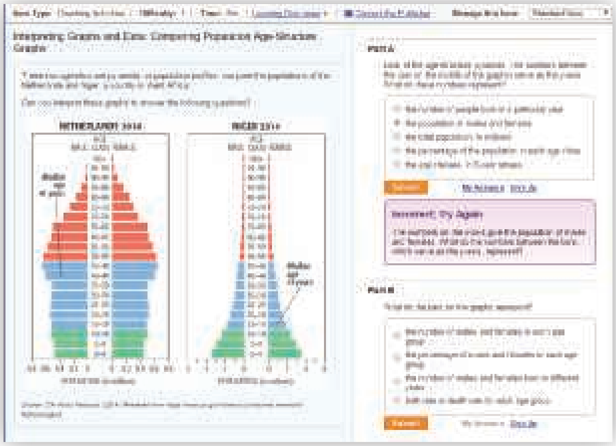


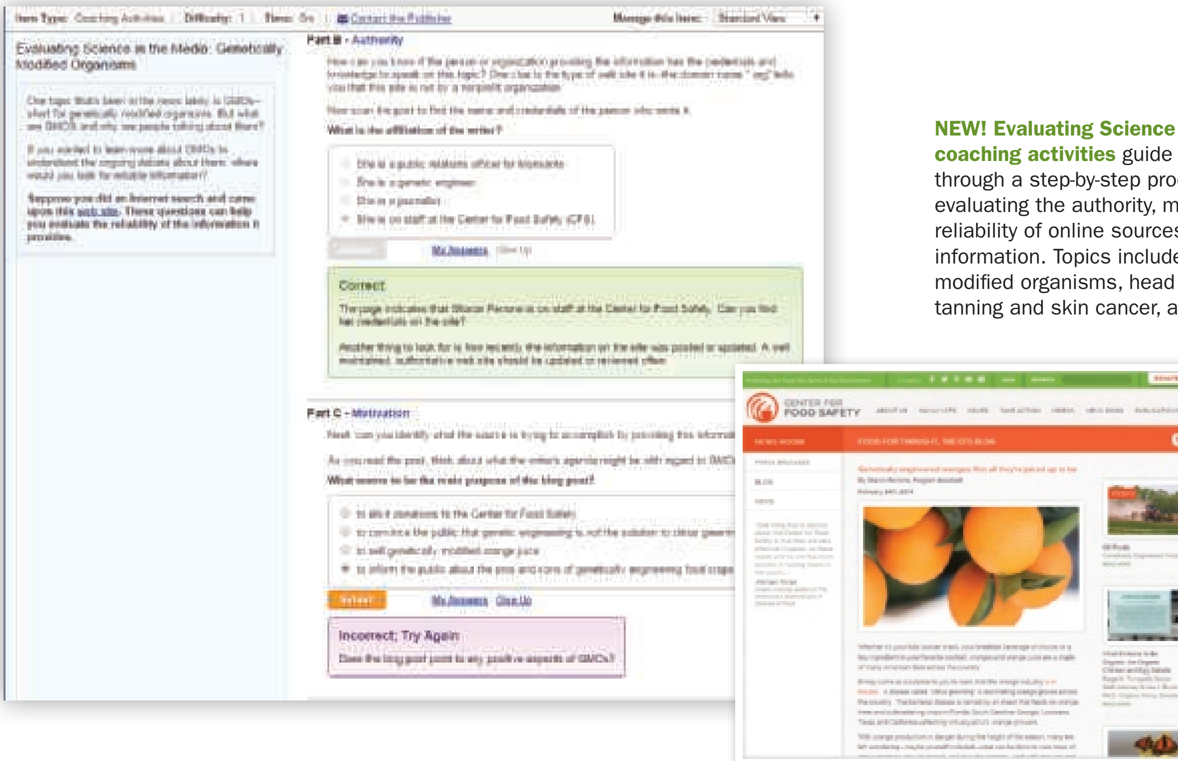
Reading Quizzes keep you on track with reading assignments. The quizzes require only 5–8 minutes for you to complete and make it possible for your instructor to understand your misconceptions before you arrive for class.



EXPANDED! Building Vocabulary Exercises help you learn the meaning of common prefixes, suffixes, and word roots, and then ask you to apply your knowledge to learn unfamiliar biology terms.

NEW! Working with Data activities ask students to analyze and apply their knowledge of biology to a graph or a set of data.





NEW! Evaluating Science in the Media coaching activities guide students through a step-by-step process for evaluating the authority, motivation, and reliability of online sources of scientific information. Topics include genetically modified organisms, head injuries, tanning and skin cancer, and more.

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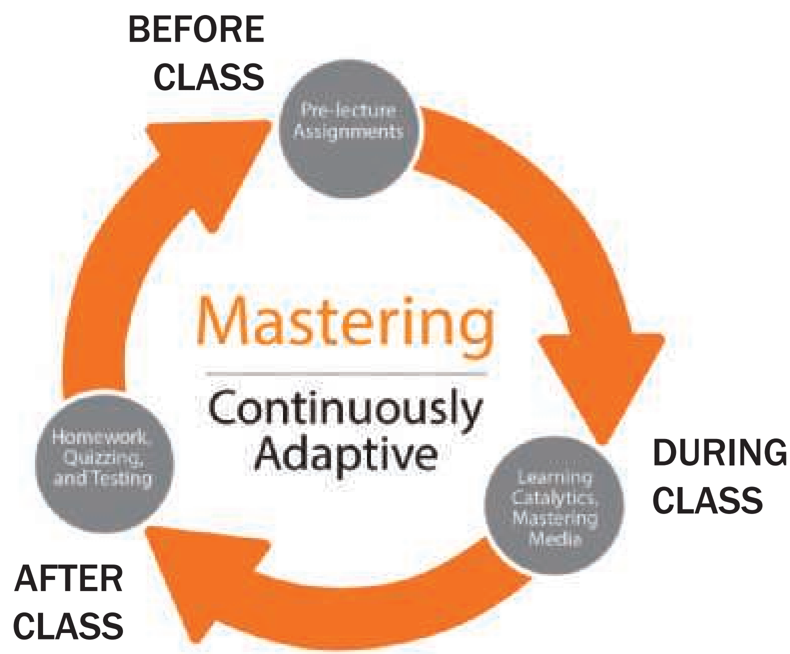

BEFORE CLASS

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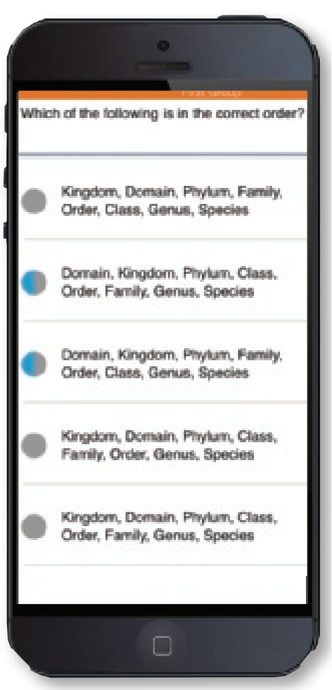
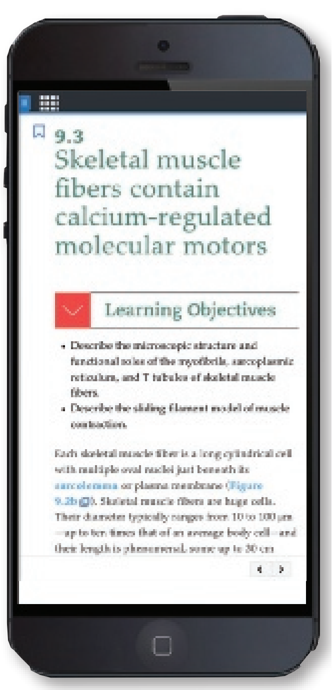


DYNAMIC STUDY MODULES



ETEXT 2.0

DURING CLASS

NEW!

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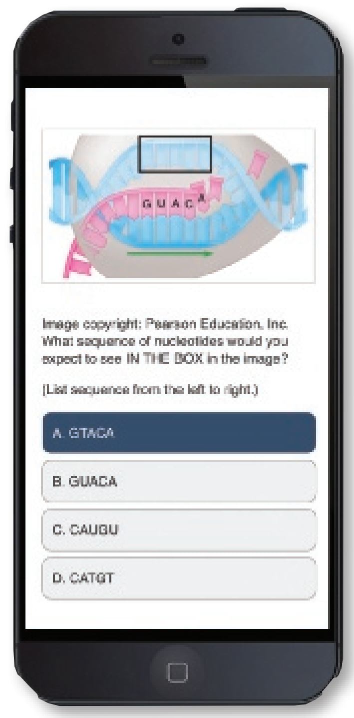
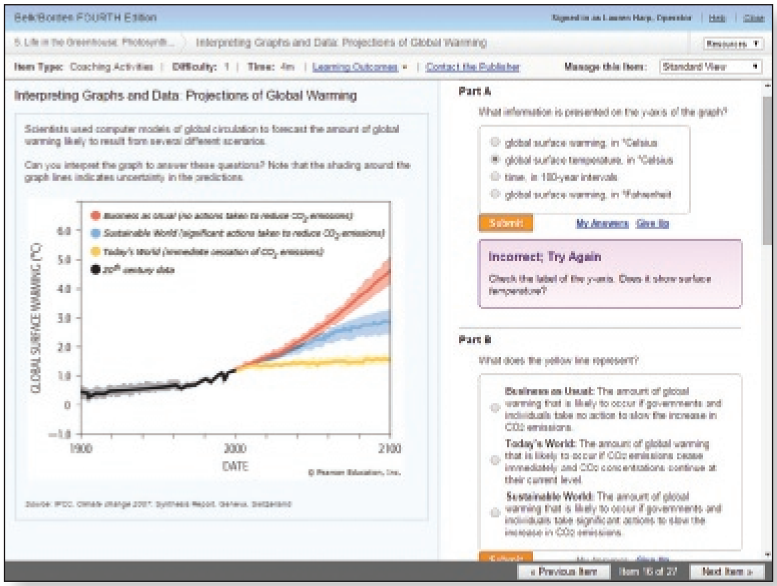


AFTER CLASS

A wide range of question types and activities are available for homework assignments, including the following NEW assignment options for the Eleventh Edition:

- **EXPANDED! Building Vocabulary activities** help you learn the meaning of common prefixes, suffixes, and word roots, and then ask you to apply your knowledge to learn unfamiliar biology terms.
- **NEW! Working with Data questions** require you to analyze and apply your knowledge of biology to a graph or set of data.
- **NEW! Evaluating Science in the Media** challenge you to evaluate various information from websites, articles, and videos.



For Instructors: New Resources for Flipped Classrooms and More

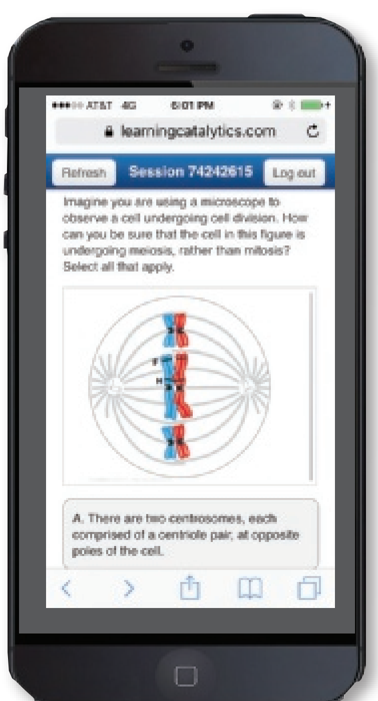
New resources save valuable time both during course prep and during class.

NEW!

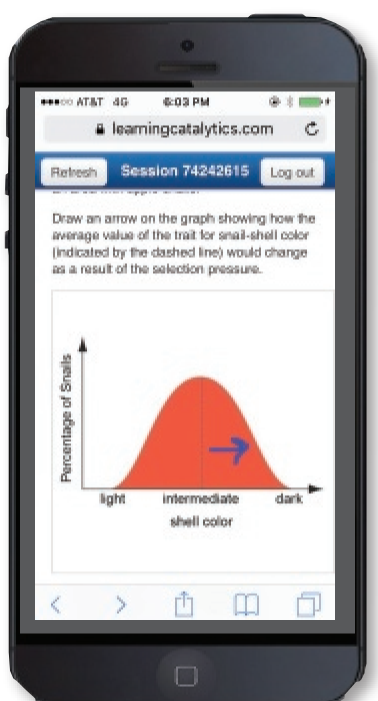
Learning Catalytics is a "bring your own device" assessment and classroom activity system that expands the possibilities for student engagement. Using Learning Catalytics, instructors can deliver a wide range of auto-gradable or open-ended questions that test content knowledge and build critical thinking skills. Eighteen different answer types provide great flexibility, including:

SKETCH/DIRECTION

MANY CHOICE



REGION



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MasteringBiology users may select from Pearson's library of Learning Catalytics questions, including questions developed specifically for *Biology: Life on Earth* 11e.

1 AN INTRODUCTION TO LIFE ON EARTH

The Ebola virus (inset) is so infectious and deadly that caregivers must protect themselves using isolation suits.

CASE STUDY

The Boundaries of Life

IN A SMALL VILLAGE in Guinea, a huge, hollow tree housed thousands of bats. The tree was a magnet for local children, who loved to play inside it and catch the bats. Scientists hypothesize that this is where two-year-old Emile Ouamouno, the first victim of the recent massive Ebola epidemic, may have become infected. Emile died in December 2013, followed by his mother and siblings. This set off a chain of transmission that has since killed more than 10,500 people, roughly half of those who became infected. The Ebola virus (see the inset photo) can lurk in rain-forest animals including certain types of bats, porcupines, chimpanzees, gorillas, and antelope—all of which are consumed in parts of Africa.

The threat of Ebola virus disease ("Ebola") strikes fear in anyone familiar with its symptoms, which often begin with fever, headache, joint and muscle aches, and stomach pains and progress to vomiting, bloody diarrhea, and organ failure. Internal hemorrhaging can leave victims bleeding from nearly every orifice. Death usually occurs within 7 to 16 days after the onset of symptoms, and there is no cure; the death rate ranges from 25% to 90%. Ebola is so contagious that caregivers wear "moon suits" to avoid contact with any body fluids from their patients.

Ebola is one of many diseases caused by viruses. Although some viral diseases, such as smallpox and polio, have been largely eradicated, others, like the common cold and influenza (flu), continue to make us miserable. Most alarming are the contagious and deadly viruses that have emerged in recent history. AIDS (caused by the human immunodeficiency virus, HIV) was first documented in 1981 in San Francisco, and Ebola was first identified in 1976 (and named after Africa's Ebola River, where one of the first outbreaks occurred). New types of flu virus emerge regularly; a few of these cause a very high mortality rate and raise fears of a widespread epidemic.

No matter how you measure it, viruses are enormously successful. Although many consist only of a small amount of genetic material surrounded by protein, viruses infect every known form of life and are the most abundant biological entity on the planet. Viruses can rapidly increase in number and spread among organisms they infect. Yet in spite of these lifelike qualities, not all scientists agree about whether to classify viruses as living organisms or as inert parasitic biological particles. The basis for this argument may surprise you: There is no universally accepted scientific definition of life. What is life, anyway?

AT A GLANCE

1.1 WHAT IS LIFE?

The word **biology** comes from the Greek roots "bio" meaning "life" and "logy" meaning "the study of" (see Appendix I for more word roots). But what is life? If you look up "life" in a dictionary, you will find definitions such as "the quality that distinguishes a vital and functioning being from a dead body," but you won't discover what that "quality" is. Life is intangible and defies simple definition, even by biologists. However, most agree that living things, or **organisms,** all share certain characteristics that, taken together, define life:

- Organisms acquire and use materials and energy.
- Organisms actively maintain organized complexity.
- Organisms sense and respond to stimuli.
- Organisms grow.
- Organisms reproduce.
- Organisms, collectively, evolve.

Nonliving objects may possess some of these attributes. Crystals can grow, and a desk lamp acquires energy from electricity and converts it to heat and light, but only living things can do them all.

The **cell** is the basic unit of life. A plasma membrane separates each cell from its surroundings, enclosing a huge variety of structures and chemicals in a fluid environment. The plasma membranes of many types of cells, including those of microorganisms and plants, are enclosed in a protective cell wall (**FIG. 1-1**). Although the most abundant organisms on Earth are **unicellular** (exist as single cells), the qualities of life are more easily visualized in **multicellular** organisms such as the water flea in **FIGURE 1-2**, an animal smaller than this letter "o." In the sections below, we introduce the characteristics of life.

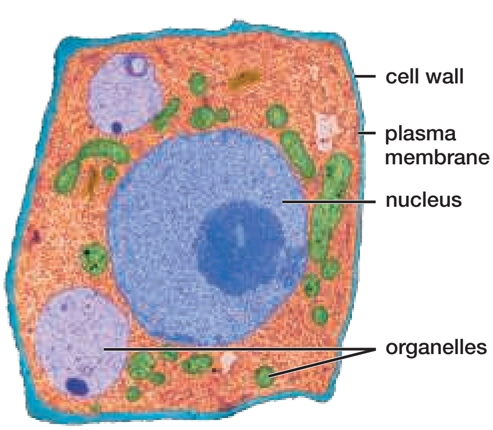
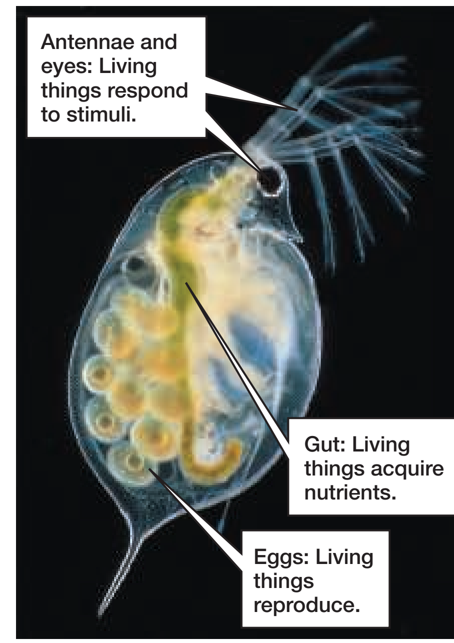


FIGURE 1-1 The cell is the smallest unit of life This artificially colored micrograph of a plant cell (a eukaryotic cell) shows a supporting cell wall (blue) that surrounds plant cells. Just inside the cell wall, the plasma membrane (found in all cells) has control over which substances enter and leave. Cells also contain several types of specialized organelles, including the nucleus, suspended within a fluid environment (orange).

FIGURE 1-2 Properties of life The water flea uses energy from photosynthetic organisms that it consumes (green material in its gut) to maintain its amazing complexity. Eyes and antennae respond to stimuli. This adult female is reproducing, and she herself has grown from an egg like those she now carries. All the adaptations that allow this water flea to survive, grow, and reproduce have been molded by evolution.



Organisms Acquire and Use Materials and Energy

Organisms obtain the materials that make up their bodies—such as minerals, water, and other simple chemical building blocks—from the air, water, soil, and, in some cases, the bodies of other living things. Because life neither creates nor destroys matter, materials are continuously exchanged and recycled among organisms and their nonliving surroundings (**FIG. 1-3**).

Organisms use energy continuously to remain alive. For example, energy is needed to move and to construct the complex molecules that make up an organism's body. Essentially all the energy that sustains life comes from sunlight. Some organisms capture solar energy directly through a process called **photosynthesis.** Photosynthetic organisms (plants and many single-celled organisms) trap and store the sun's energy for their own use. The energy stored in their bodies also powers all nonphotosynthetic organisms. So energy flows in a one-way path from the sun to photosynthetic organisms to all other forms of life (see Fig. 1-3). Some energy is lost as heat at each transfer from one organism to another, making less energy available with each transfer.

Organisms Actively Maintain Organized Complexity

For both the books and papers on your desk and the fragile and dynamic intricacy of a cell, organization tends to disintegrate unless energy is used to maintain it (see Chapter 6). Living things, representing the ultimate in organized complexity, continuously use energy to maintain themselves.

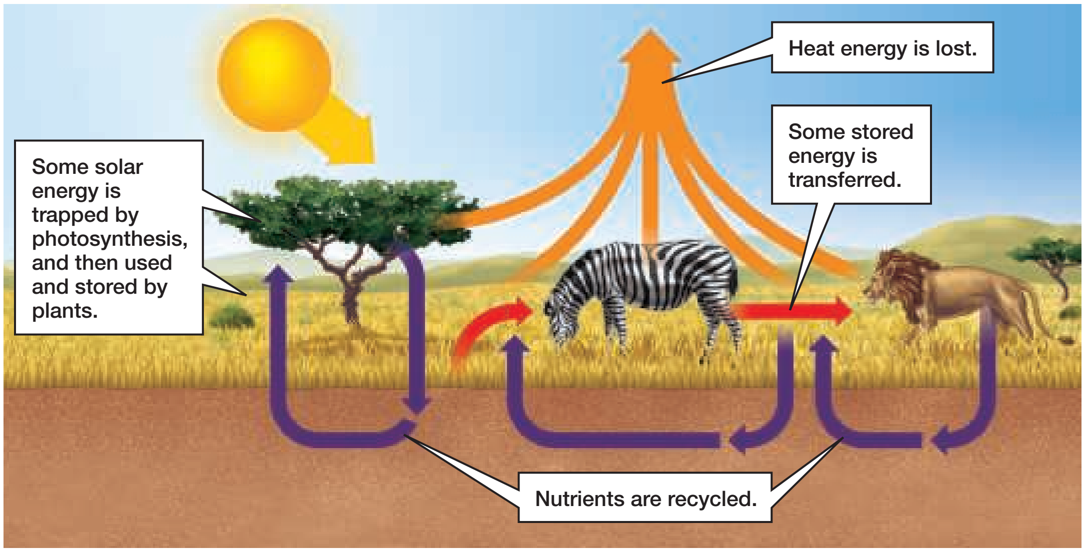


FIGURE 1-3 The flow of energy and the recycling of nonliving nutrients

THINK CRITICALLY
Describe the source of the energy stored in the meat and the bun of a hamburger, and explain how the energy got from the source to the two foodstuffs.

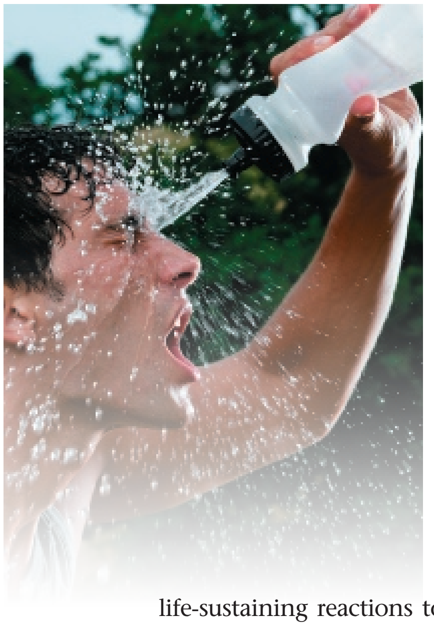


FIGURE 1-4 Organisms maintain relatively constant internal conditions Evaporative cooling by water, both from sweat and from a bottle, helps this athlete maintain his body temperature during vigorous exercise.

The ability of an organism to maintain its internal environment within the limits required to sustain life is called **homeostasis.** To maintain homeostasis, cell membranes constantly pump specific substances in and others out. People and other mammals use both physiological and behavioral mechanisms to maintain the narrow temperature range that allows life-sustaining reactions to occur in their cells (**FIG. 1-4**). Life, then, requires very precise internal conditions maintained by a continuous expenditure of energy.

Organisms Sense and Respond to Stimuli

To obtain energy and nutrients, organisms must sense and respond to stimuli in their environments. Animals use specialized cells to detect light, temperature, sound, gravity, touch, chemicals, and many other stimuli from their external and internal surroundings. For example, when your brain detects a low level of sugar in your blood (an internal stimulus), it causes your mouth to water at the smell of food (an external stimulus). Plants, fungi, and single-celled organisms use very different mechanisms that are equally effective for their needs (**FIG. 1-5**). Even many bacteria, the smallest and simplest life-forms, can move toward favorable conditions and away from harmful substances.

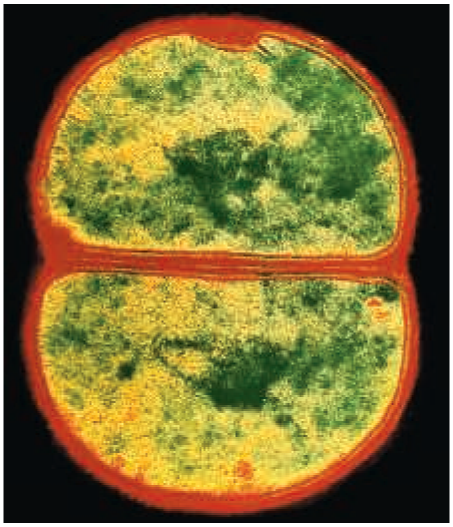
Organisms Grow

At some time in its life, every organism grows. The water flea in Figure 1-2 grew from the size of one of the eggs you see in its body. Single-celled organisms such as bacteria grow to about double their original size, copy their genetic material, and then divide in half to reproduce. Animals and plants use a similar process to produce more cells within their bodies, repeating the sequence until growth stops. Individual cells can also contribute to the growth of an organism by increasing in size, as occurs in muscle and fat cells in animals and in food storage cells in plants.

Organisms Reproduce

Organisms reproduce in a variety of ways (**FIG. 1-6**). These include dividing in half, producing seeds, bearing live young, and producing eggs (see Fig. 1-2). The end result is always the same: new versions of the parent organisms that inherit the instructions for producing and maintaining their particular form of life. These instructions—copied in every cell and passed on to descendants—are carried in the unique structure

FIGURE 1-5 Bending toward the light Plants perceive and often bend toward light, which provides them with the energy they need to survive.



(a) Dividing *Streptococcus* bacterium

(b) Dandelion producing seeds

(c) Panda with its baby

FIGURE 1-6 Organisms reproduce

of the hereditary molecule **deoxyribonucleic acid (DNA)** (**FIG. 1-7**; see Chapter 12). The complete set of DNA molecules contained in each cell provides a detailed instruction manual for life, much like an architectural blueprint provides instructions for constructing a building.

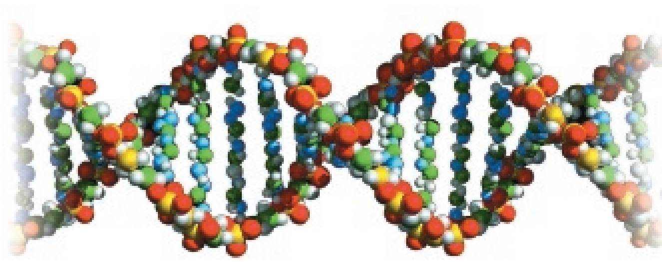


FIGURE 1-7 DNA As James Watson, the codiscoverer of the structure of DNA, stated: "A structure this pretty just had to exist."

Organisms, Collectively, Have the Capacity to Evolve

A simple definition of **evolution** is the change in DNA that occurs in a population over time. Through the course of generations, changes in DNA within any **population** (a group of the same type of organism inhabiting the same area) are inevitable. In the words of biologist Theodosius Dobzhansky, "Nothing in biology makes sense except in the light of evolution." The next section provides a brief introduction to evolution—the unifying concept of biology.

CHECK YOUR LEARNING

Can you …

- explain the characteristics that define life?
- explain why these characteristics are necessary to sustain life?
- describe how reproduction allows evolution to occur?

CASE STUDY CONTINUED

The Boundaries of Life

Are viruses alive? Viruses release their genetic material inside cells and then hijack the infected cell's energy supplies and biochemical machinery, turning the cell into a kind of factory that churns out many copies of viral parts. These parts assemble into an army of virus particles. The newly formed viruses then emerge from the host cell, often rupturing it in the process. Some types of viruses, including HIV and the Ebola virus, acquire an outer envelope made of the infected cell's plasma membrane as they emerge. Viruses do not obtain or use their own energy or materials, maintain themselves, or grow. Therefore, viruses do not meet our criteria for life. They do, however, possess a few characteristics of life: Viruses respond to stimuli by binding to specific sites on the cells they attack, and some scientists consider viral replication a form of reproduction. Viruses also evolve, often with stunning speed. How does evolution occur in viruses and other biological entities?

1.2 WHAT IS EVOLUTION?

Evolution is genetic change in a population over time. Cumulative changes over vast stretches of time explain the amazing diversity of organisms that now share this planet. The scientific theory of evolution was formulated in the mid-1800s by two English naturalists, Charles Darwin and Alfred Russel Wallace. Since that time, it has been supported by fossils, geological studies, radioactive dating of rocks, genetics, molecular biology, biochemistry, and breeding experiments. Evolution not only explains the enormous diversity of life, but also accounts for the remarkable similarities among different types of organisms. For example, people share many features with chimpanzees, and the sequence of our DNA is nearly identical to that of chimpanzees. This similarity is

FIGURE 1-8 Chimpanzees and people are closely related

strong evidence that people and chimps descended from a common ancestor, but the obvious differences (**FIG. 1-8**) reflect the differences in our evolutionary paths.

Three Natural Processes Underlie Evolution

Evolution is an automatic and inevitable outcome of three natural occurrences: (1) differences among members of a population, (2) inheritance of these differences by offspring, and (3) natural selection, the process by which individuals that inherit certain characteristics tend to survive and reproduce better than other individuals. Let's take a closer look at these three factors.

Mutations Are the Source of Differences in DNA

Look around at your classmates and notice how different they are, or observe how dogs differ in size, in shape, and in the color, length, and texture of their coats. Although some of this variation (particularly among your classmates) is due to differences in environment and lifestyle, much of it results from differences in genes. **Genes,** which are specific segments of DNA, are the basic units of heredity. Before a cell divides, all of its DNA is copied, allowing its genes to be passed along to both resulting cells. Just as you would make mistakes if you tried to copy a blueprint by hand, cells make some errors as they copy their DNA. Changes in genes, such as those caused by these random copying errors, are called **mutations.** Mutations can also result from damage to DNA, caused, for example, by ultraviolet rays from sunlight, radiation released from a damaged nuclear power plant, or toxic chemicals from cigarette smoke. Just as changes to a blueprint will cause changes in the structure built from it, so may a new cell with altered DNA differ from its parent cell.

Some Mutations Are Inherited

Mutations that occur in sperm or egg cells may result in transmission of altered DNA from parent to offspring. Each cell in the offspring will carry the inherited mutation. Most mutations to genes are either harmful or neutral. For example, genetic diseases such as hemophilia, sickle-cell anemia, and cystic fibrosis are caused by harmful mutations. Other mutations have no observable effect or change the organism in a way that is *neutral,* neither harmful nor beneficial. Almost all of the inherited variability among traits—such as human eye color—is caused by neutral mutations that occurred in the distant past and have been passed along harmlessly through generations. On rare occasions, however, an inherited mutation changes a gene in a way that helps offspring to survive and reproduce more successfully than those lacking the mutation. These infrequent events provide the raw material for evolution.

Some Inherited Mutations Help Individuals Survive and Reproduce

The most important process in evolution is natural selection, which acts on the natural variability in traits. **Natural selection** is the process by which organisms with certain inherited traits survive and reproduce better than others in a given environment. As a result, the advantageous inherited traits become increasingly common in the population as generations pass. Because these traits are caused by differences in genes, the genetic makeup of the population as a whole will change over time; that is, the population will evolve. Consider a likely scenario of natural selection. Imagine that ancient beavers had short front teeth like most other mammals. If a mutation caused one beaver's offspring to grow longer front teeth, these offspring would have gnawed down trees more efficiently, built bigger dams and lodges, and eaten more bark than beavers that lacked the mutation. These long-toothed beavers would have been better able to survive and would have raised more offspring that would inherit the genes for longer front teeth. Over time, long-toothed beavers would have become increasingly common; after many generations, all beavers would have long front teeth.

Structures, physiological processes, or behaviors that help an organism survive and reproduce in a particular environment are called **adaptations.** Most of the features that we admire so much in other life-forms, such as the fleet, agile limbs of deer, the broad wings of eagles, and the mighty trunks of redwood trees, are adaptations. Adaptations help organisms escape predators, capture prey, reach the sunlight, or accomplish other feats that help ensure their survival and reproduction. The huge array of adaptations found in living things today was molded by natural selection acting on random mutations.

But how did life's diversity, including deer, eagles, redwoods, and people, all arise from the first single-celled life that appeared billions of years ago? Natural selection is not uniform; a trait that is adaptive in one environment may not be helpful (or may even be a hindrance) in a different setting. After Darwin observed different but closely related organisms on clusters of islands, he hypothesized that different forms of life may evolve if a population becomes fragmented and groups of individuals are subjected to different environments. For example, a violent storm may carry some individuals from the mainland to an offshore island. The mainland and the island populations will initially consist of the same **species** (organisms of the same type that can interbreed). But if the island's environment differs from that of

FIGURE 1-9 A fossil from a newly discovered dinosaur, *Titanosaurus* The most widely accepted hypothesis for the extinction of dinosaurs about 65 million years ago is a massive meteorite strike that rapidly and radically altered their environment. This thigh bone, estimated to be 95 million years old, is from a plant-eating giant with an estimated length of 130 feet (40 meters) and a weight of about 176,000 pounds (80 metric tons).

THINK CRITICALLY The largest dinosaurs were plant-eaters. Based on Figure 1-3, can you suggest a reason why?

the mainland, the newcomers will be subjected to different forces of natural selection; as a result, they will evolve different adaptations. These differences may eventually become great enough that the two populations can no longer interbreed; a new species will have evolved.

What helps an organism survive today may become a liability in the future. If environments change—for example, as global climate change occurs—the traits that best adapt organisms to their environments will change as well. In the case of global climate change, if a random mutation helps an organism survive and reproduce in a warmer climate, the mutation will be favored by natural selection and will become more common in the population with each new generation.

If mutations that help an organism to adapt do not occur, a changing environment may doom a species to **extinction**—the complete elimination of this form of life. Dinosaurs flourished for 100 million years, but because they did not evolve fast enough to adapt to rapidly changing conditions, they became extinct (**FIG. 1-9**). In recent decades, human activities such as burning fossil fuels and converting tropical forests to farmland have drastically accelerated the rate of environmental change. Mutations that better adapt organisms to these altered environments are quite rare, and consequently the rate of extinction has increased dramatically.

CHECK YOUR LEARNING

Can you …

- explain what mutations are, how they occur, what allows them to be inherited, and what general types of changes mutations can produce?
- explain how natural processes lead inevitably to evolution?
- describe how a new species can be produced by natural selection?

CASE STUDY CONTINUED

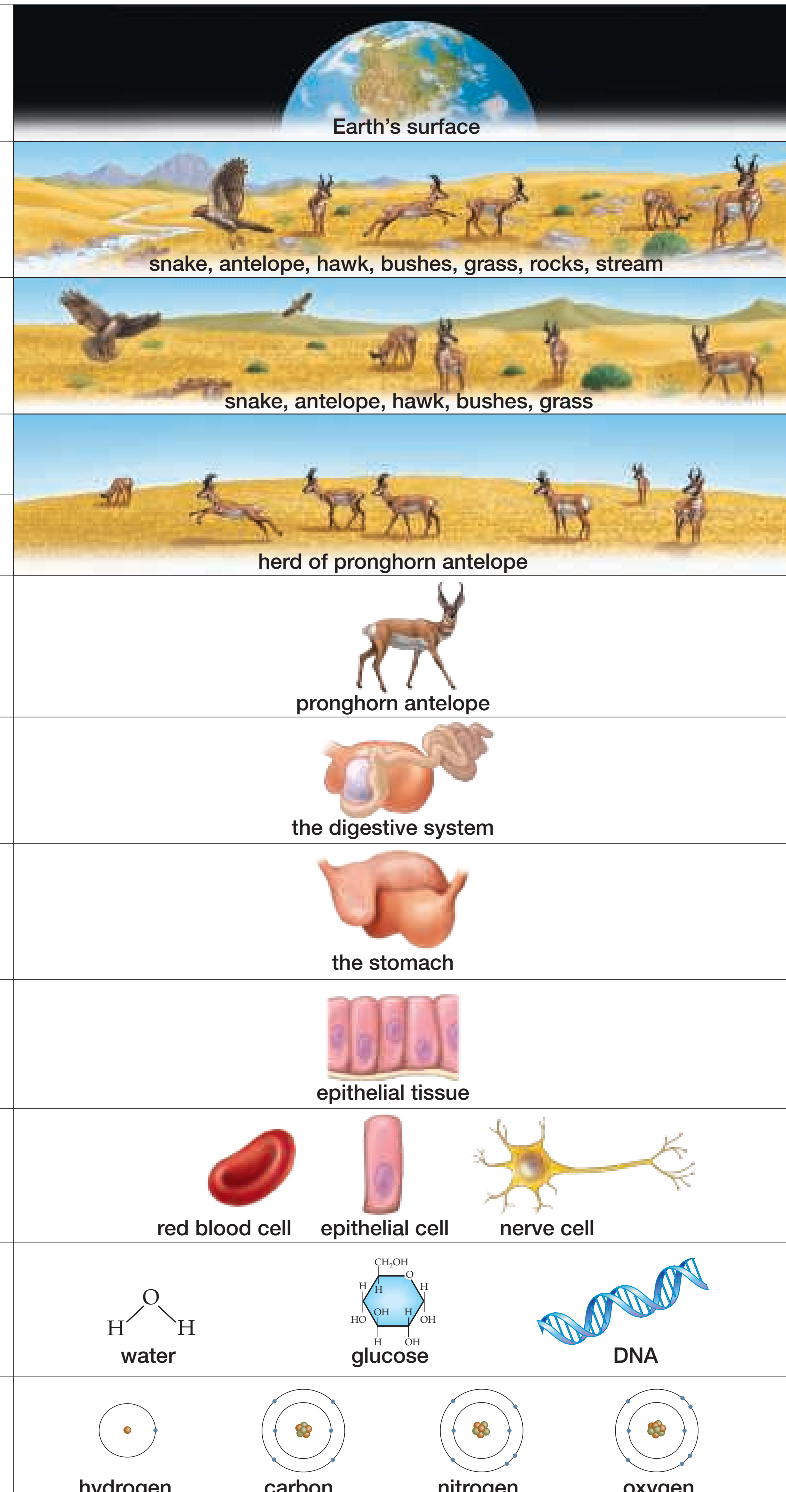
The Boundaries of Life

One lifelike property of viruses is their capacity to evolve. Through evolution, viruses sometimes become more infectious or more deadly, or they may gain the ability to infect new hosts. Certain types of viruses, including Ebola, HIV, and flu, are very sloppy in copying their genetic material and mutate about 1,000 times as often as the average animal cell. One consequence is that viruses such as flu evolve rapidly; flu shots must immunize you against different types of flu every year. Likewise, more than 200 different viruses can cause symptoms of the "common cold," explaining why you keep getting new colds throughout life. HIV in an infected person can produce up to 10 billion new viruses daily, with 10 million of these carrying a random mutation. Inevitably, some of these mutations will produce resistance to an antiviral drug. Therefore, antiviral drugs act as agents of natural selection that promote the survival and successful replication of drug-resistant viruses. For this reason, HIV victims are given "cocktails" of three or four different drugs; resistance to all of them would require multiple specific mutations to occur in the same virus, an enormously unlikely event.

1.3 HOW DO SCIENTISTS STUDY LIFE?

The science of biology encompasses many different areas of inquiry, each requiring different types of specialized knowledge. In fact, biology is not a single field, but many—linked by the amazing complexity of life.

Biosphere	All life on Earth and the nonliving portions of Earth that support life
Ecosystem	A community together with its nonliving surroundings
Community	Populations of different species that live in the same area and interact with one another
Species	All organisms that are similar enough to interbreed
Population	All the members of a species living in the same area
Multicellular organism	An individual living thing composed of many cells
Organ system	Two or more organs working together in the execution of a specific bodily function
Organ	A structure usually composed of several tissue types that form a functional unit
Tissue	A group of similar cells that perform a specific function
Cell	The smallest unit of life
Molecule	A combination of atoms
Atom	The smallest particle of an element that retains the properties of that element



▲ **FIGURE 1-10 Levels of biological organization** Each level provides building blocks for the one above it, which has new properties that emerge from the interplay of the levels below.

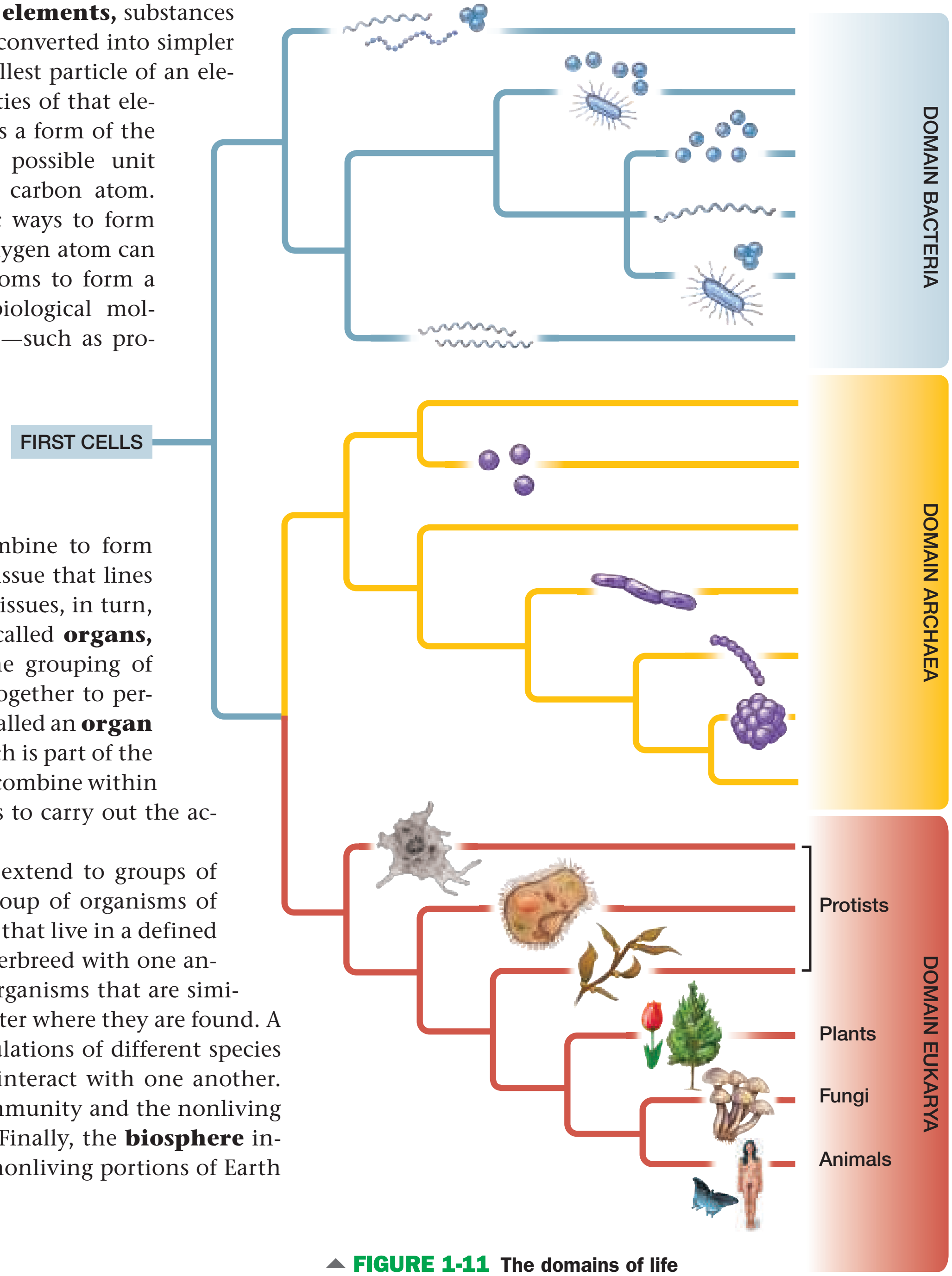
THINK CRITICALLY What current, ongoing environmental change is likely to affect the entire biosphere?

Life May Be Studied at Different Levels

Let's look at the levels of organization that comprise life on Earth (**FIG. 1-10**). Biologists conduct research at nearly every level, from complex biological molecules such as DNA to entire ecosystems (for example, how forest ecosystems may be altered by climate change).

Each level of organization provides a foundation for the one above it, and each higher level has new, more inclusive properties. All matter consists of **elements,** substances that cannot be broken down or converted into simpler substances. An **atom** is the smallest particle of an element that retains all the properties of that element. For example, a diamond is a form of the element carbon. The smallest possible unit of a diamond is an individual carbon atom. Atoms may combine in specific ways to form **molecules;** for example, one oxygen atom can combine with two hydrogen atoms to form a molecule of water. Complex biological molecules containing carbon atoms—such as proteins and DNA—form the building blocks of cells, which are the basic units of life. Although many organisms exist as single cells, in multicellular organisms, cells of a similar type may combine to form **tissues,** such as the epithelial tissue that lines the stomach. Different types of tissues, in turn, unite to form functional units called **organs,** such as the entire stomach. The grouping of two or more organs that work together to perform a specific body function is called an **organ system;** for example, the stomach is part of the digestive system. Organ systems combine within complex multicellular organisms to carry out the activities of life.

Levels of organization also extend to groups of organisms. A population is a group of organisms of the same type (the same species) that live in a defined area where they interact and interbreed with one another. A species consists of all organisms that are similar enough to interbreed, no matter where they are found. A **community** is formed by populations of different species that live in the same area and interact with one another. An **ecosystem** consists of a community and the nonliving environment that surrounds it. Finally, the **biosphere** includes all life on Earth and the nonliving portions of Earth that support life.



▲ **FIGURE 1-11 The domains of life**

Biologists Classify Organisms Based on Their Evolutionary Relationships

Although all forms of life share certain characteristics, evolution has produced an amazing variety of life-forms. Scientists classify organisms based on their evolutionary relatedness, placing them into three major groups, or **domains:** Bacteria, Archaea, and Eukarya (**FIG. 1-11**).

This classification reflects fundamental differences among cell types. Members of both Bacteria and Archaea consist of a single, simple cell. At the molecular level, however, there are fundamental differences between them that indicate that they are only distantly related. In contrast to the simple cells of Bacteria and Archaea, members of Eukarya have bodies composed of one or more extremely complex cells. The domain Eukarya includes a diverse collection of organisms collectively known as *protists* and the fungi, plants, and animals. (You will learn far more about life's incredible diversity and how it evolved in Unit 3.)

Cell Type Distinguishes the Bacteria and Archaea from the Eukarya

All cells are surrounded by a thin sheet of molecules called the **plasma membrane** (see Fig. 1-1). All contain the hereditary material DNA. Cells also contain **organelles,** structures specialized to carry out specific functions such as helping to synthesize large molecules, digesting food molecules, or obtaining energy.

There are two fundamentally different types of cells: eukaryotic and prokaryotic. **Eukaryotic** cells are extremely complex and contain a variety of organelles, many of which are surrounded by membranes. The term "eukaryotic" comes from Greek words meaning "true" ("eu") and "nucleus" ("kary"). As the name suggests, the **nucleus,** a membrane-enclosed organelle that contains the cell's DNA, is a prominent feature of eukaryotic cells (see Fig. 1-1). All members of the Eukarya are composed of eukaryotic cells. **Prokaryotic** cells, which comprise the domains Bacteria and Archaea, are far simpler and generally much smaller than eukaryotic cells, and they lack organelles enclosed by membranes. As their name—meaning "before" ("pro") the nucleus—suggests, the DNA of prokaryotic cells is not confined within a nucleus. Although they are invisible to the naked eye, the most abundant forms of life are found in the domains Bacteria and Archaea, which consist entirely of prokaryotic cells.

Multicellularity Occurs Only Among the Eukarya

Members of the domains Bacteria and Archaea are unicellular. Although some form strands, mats, or biofilms (thin layers of bacteria), there is relatively little communication, cooperation, or organization among them compared to multicellular organisms—which are only found among the Eukarya. Although protists are eukaryotic and many are unicellular, all plants and animals and nearly all fungi are multicellular; their lives depend on intimate communication and cooperation among numerous specialized cells.

Biologists Use the Binomial System to Name Organisms

To provide a unique scientific name for each form of life, biologists use a **binomial system** (literally "two names") consisting of the genus (a group of closely related species) and the species. The genus name is capitalized, and both names are italicized and based on Latin or Greek word roots. The animal in Figure 1-2 has the common name "water flea," but there are many types of water fleas, and people who study them need to be precise. So this water flea has been given the scientific name *Daphnia longispina,* placing it in the genus *Daphnia* (which includes many similar species of water fleas) and the species *longispina* (referring to its long spine). People are classified as *Homo sapiens;* we are the only surviving members of our genus.

CHECK YOUR LEARNING

Can you ...

- describe the levels of biological organization?
- explain how scientists name and categorize diverse forms of life?
- describe the fundamental differences between prokaryotic and eukaryotic cells?

1.4 WHAT IS SCIENCE?

Science can be defined as the systematic inquiry—through observation and experiment—into all aspects of the physical universe.

Science Is Based on General Underlying Principles

Three basic principles provide the foundation for scientific inquiry. The first is that all events can be traced to natural causes. In ancient times—in contrast—it was common to believe that supernatural forces were responsible for natural events that seemed to defy explanation. Ancient Greeks explained lightning bolts as weapons hurled by the god Zeus and attributed epileptic seizures to a visitation from the gods. Today, science tells us that lightning is a massive electrical discharge, and epilepsy is a brain disorder caused by uncontrolled firing of nerve cells. Science is an unending quest to discover the causes of phenomena that we don't yet understand.

The second principle of science is that natural laws do not change over time or distance. The laws of gravity, for example, are the same today as they were 10 billion years ago, and they apply everywhere in our universe.

The third principle is that scientific findings are "value neutral." Science, in its ideal form, provides us with facts that are independent of subjective values; in other words, scientific data exist outside of any belief system. For example, science can describe in detail the events that occur when a human egg is fertilized, but cannot tell us whether a fertilized egg is a person.

The Scientific Method Is an Important Tool of Scientific Inquiry

To learn about the world, scientists in many disciplines, including biology, use some version of the **scientific method.** This consists of six interrelated elements: *observation*, *question*, *hypothesis*, *prediction*, *experiment*, and *conclusion*. Scientific inquiry begins with an **observation** of a specific phenomenon. The observation, in turn, leads to a **question:** "What caused this?" After carefully studying earlier investigations, thinking, and often conversing with colleagues, the investigator forms a hypothesis. A **hypothesis** is a proposed explanation for the phenomenon, based on available evidence. To be useful, the hypothesis must lead to a **prediction,** which is the expected outcome of testing if the hypothesis is correct. The prediction is tested by carefully designed additional observations or carefully controlled manipulations called **experiments.** Experiments produce results that either support or refute the hypothesis, allowing the scientist to reach a **conclusion** about whether the hypothesis is valid or not. For the conclusion to be valid, the experiment and its results must be repeatable not only by the original researcher but also by others.

We use less formal versions of the scientific method in our daily lives. For example, suppose you are late for an