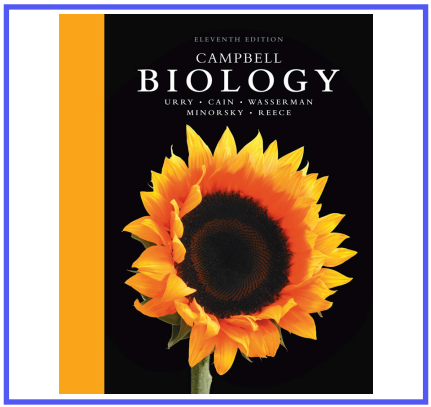


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We are honored to present the Eleventh Edition of *Campbell Biology*. For the last three decades, *Campbell Biology* has been the leading college text in the biological sciences. It has been translated into 19 languages and has provided millions of students with a solid foundation in college-level biology. This success is a testament not only to Neil Campbell's original vision but also to the dedication of hundreds of reviewers (listed on pages xxviii–xxxi), who, together with editors, artists, and contributors, have shaped and inspired this work.



Our goals for the Eleventh Edition include:

- **increasing visual literacy** through new figures, questions, and exercises that build students' skills in understanding and creating visual representations of biological structures and processes
- asking students to **practice scientific skills** by applying scientific skills to real-world problems
- **supporting instructors** by providing teaching modules with tools and materials for introducing, teaching, and assessing important and often challenging topics
- **integrating text and media** to engage, guide, and inform students in an active process of inquiry and learning

Our starting point, as always, is our commitment to crafting text and visuals that are accurate, are current, and reflect our passion for teaching biology.

New to This Edition

Here we provide an overview of the new features that we have developed for the Eleventh Edition; we invite you to explore pages ix–xxvi for more information and examples.

- **Visualizing Figures** and **Visual Skills Questions** give students practice in interpreting and creating visual representations in biology. The Visualizing Figures have embedded questions that guide students in exploring how diagrams, photographs, and models represent and reflect biological systems and processes. Assignable questions are also available in **MasteringBiology** to give students practice with the visual skills addressed in the figures.
- **Problem-Solving Exercises** challenge students to apply scientific skills and interpret data in solving real-world problems. These exercises are designed to engage students through compelling case studies and provide practice with data analysis skills. Problem-Solving Exercises have assignable versions in **MasteringBiology**. Some also have more extensive "Solve It" investigations to further explore a given topic.
- **Ready-to-Go Teaching Modules** on key topics provide instructors with assignments to use before and after class, as well as in-class activities that use clickers or Learning Catalytics™ for assessment.
- **Integrated text and media**: Media references in the printed book direct students to the wealth of online self-study resources available to them in the **Study Area** section of **MasteringBiology**. In eText 2.0 (which will be available for Fall 2017 classes), these resources will also be integrated directly into the eText. The new online learning tools include:
  - **Get Ready for This Chapter** questions provide a quick check of student understanding of the background information needed to learn a new chapter's content, with feedback to bolster their preparation.
  - **Figure Walkthroughs** guide students through key figures with narrated explanations, figure markups, and questions that reinforce important points. Additional questions can be assigned in **MasteringBiology**.
  - More than **450 animations and videos** bring biology to life. These include resources from **HHMI BioInteractive** that engage students in topics from the discovery of the double helix to evolution.
  - QR codes and URLs within the Chapter Review provide easy access to **Vocabulary Self-Quizzes** and **Practice Tests** for each chapter that can be used on smartphones, tablets, and computers.
  - **Interviews** from the First Edition through the Eleventh Edition of *Campbell Biology* are referenced in the chapter where they are most relevant. The interviews show students the human side of science by featuring diverse scientists talking about how they became interested in what they study, how they began, and what inspires them.
- The impact of **climate change** at all levels of the biological hierarchy is explored throughout the text, starting with a new figure (Figure 1.12) and discussion in Chapter 1 and concluding with a new Make Connections Figure (Figure 56.30) and expanded coverage on causes and effects of climate change in Chapter 56.
- As in each new edition of *Campbell Biology*, the Eleventh Edition incorporates **new content** and **pedagogical improvements**. These are summarized on pp. vi–viii, following this Preface. Content updates reflect rapid, ongoing changes in technology and knowledge in the fields of genomics, gene editing technology (CRISPR), evolutionary

biology, microbiology, and more. In addition, significant revisions to Unit 8, Ecology, improve the conceptual framework for core ecological topics (such as population growth, species interactions, and community dynamics) and more deeply integrate evolutionary principles.

Our Hallmark Features

Teachers of general biology face a daunting challenge: to help students acquire a conceptual framework for organizing an ever-expanding amount of information. The hallmark features of *Campbell BIOLOGY* provide such a framework, while promoting a deeper understanding of biology and the process of science. As such, they are well aligned with the core competencies outlined by the 2009 **Vision and Change** national conference. Furthermore, the core concepts defined by Vision and Change have close parallels in the unifying themes that are introduced in Chapter 1 and integrated throughout the book. Chief among the themes of both Vision and Change and *Campbell BIOLOGY* is **evolution.** Each chapter of this text includes at least one Evolution section that explicitly focuses on evolutionary aspects of the chapter material, and each chapter ends with an Evolution Connection Question and a Write About a Theme Question.

To help students distinguish the "forest from the trees," each chapter is organized around a framework of three to seven carefully chosen **Key Concepts**. The text, Concept Check Questions, Summary of Key Concepts, and MasteringBiology resources all reinforce these main ideas and essential facts.

Because text and illustrations are equally important for learning biology, **integration of text and figures** has been a hallmark of this text since the First Edition. In addition to the new Visualizing Figures, our popular Exploring Figures and Make Connections Figures epitomize this approach. Each Exploring Figure is a learning unit of core content that brings together related illustrations and text. Make Connections Figures reinforce fundamental conceptual connections throughout biology, helping students overcome tendencies to compartmentalize information. The Eleventh Edition features two new Make Connections Figures. There are also Guided Tour Figures that walk students through complex figures as an instructor would.

To encourage **active reading** of the text, *Campbell BIOLOGY* includes numerous opportunities for students to stop and think about what they are reading, often by putting pencil to paper to draw a sketch, annotate a figure, or graph data. Active reading questions include Visual Skills Questions, Draw It Questions, Make Connections Questions, What If? Questions, Figure Legend Questions, Summary Questions, Synthesize Your Knowledge Questions, and Interpret the Data Questions. Answering these questions requires students to write or draw as well as think and thus helps develop the core competency of communicating science.

Finally, *Campbell BIOLOGY* has always featured **scientific inquiry**, an essential component of any biology course. Complementing stories of scientific discovery in the text narrative and the unit-opening interviews, our standard-setting Inquiry Figures deepen the ability of students to understand how we know what we know. Scientific Inquiry Questions give students opportunities to practice scientific thinking, along with the Problem-Solving Exercises, Scientific Skills Exercises, and Interpret the Data Questions. Together, these activities provide students practice in both applying the process of science and using quantitative reasoning, addressing additional core competencies outlined in Vision and Change.

MasteringBiology®

MasteringBiology, the most widely used online assessment and tutorial program for biology, provides an extensive library of homework assignments that are graded automatically. In addition to the **new Get Ready for This Chapter Questions, Figure Walkthroughs, Problem-Solving Exercises, and Visualizing Figures**, MasteringBiology offers Dynamic Study Modules, Adaptive Follow-Up Assignments, Scientific Skills Exercises, Interpret the Data Questions, Solve It Tutorials, HHMI BioInteractive Short Films, BioFlix® Tutorials with 3-D Animations, Experimental Inquiry Tutorials, Interpreting Data Tutorials, BLAST Tutorials, Make Connections Tutorials, Video Field Trips, Video Tutor Sessions, Get Ready for Biology, Activities, Reading Quiz Questions, Student Misconception Questions, 4,500 Test Bank Questions, and MasteringBiology Virtual Labs. MasteringBiology also includes the *Campbell BIOLOGY* eText, Study Area, Instructor Resources, and Ready-to-Go Teaching Modules. See pages ix–xxiii and www.masteringbiology.com for more details.

Our Partnership with Instructors and Students

A core value underlying our work is our belief in the importance of a partnership with instructors and students. One primary way of serving instructors and students, of course, is providing a text that teaches biology well. In addition, Pearson offers a rich variety of instructor and student resources, in both print and electronic form (see pp. ix–xxiii). In our continuing efforts to improve the book and its supplements, we benefit tremendously from instructor and student feedback, not only in formal reviews from hundreds of scientists, but also via e-mail and other avenues of informal communication.

The real test of any textbook is how well it helps instructors teach and students learn. We welcome comments from both students and instructors. Please address your suggestions to:

Lisa Urry (Chapter 1 and Units 1–3)
lurry@mills.edu
Michael Cain (Units 4, 5, and 8)
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Peter Minorsky (Unit 6)
pminorsky@mercy.edu
Steven Wasserman (Unit 7)
stevenw@ucsd.edu

This section highlights selected new content and pedagogical changes in *Campbell Biology*, Eleventh Edition.

CHAPTER 1 Evolution, the Themes of Biology, and Scientific Inquiry

Chapter 1 opens with a new introduction to a case study on the evolution of coloration in mice. New text and a new photo (Figure 1.12) relate climate change to species survival.

UNIT 1 THE CHEMISTRY OF LIFE

In Unit 1, new content engages students in learning this foundational material. The opening of Chapter 3 and new **Figure 3.7** show organisms affected by **loss of Arctic sea ice**. Chapter 5 has updates on lactose intolerance, *trans* fats, the effects of diet on blood cholesterol, protein sequences and structures, and intrinsically disordered proteins. New Visualizing Figure 5.16 helps students understand various ways proteins are depicted. A new Problem-Solving Exercise engages students by having them compare DNA sequences in a case of possible fish fraud.

Figure 3.7 Effects of climate change on the Arctic.



UNIT 2 THE CELL

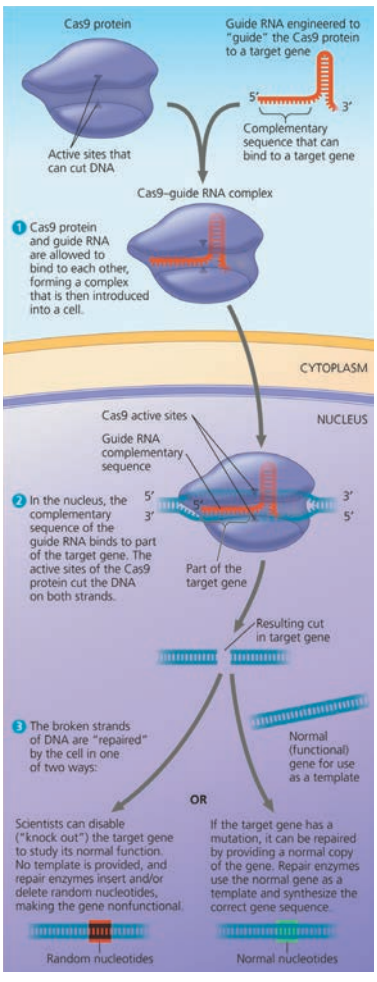
Our main goal for this unit was to make the material more accessible and inviting to students. New Visualizing Figure 6.32 shows the profusion of molecules and structures in a cell, all drawn to scale. In Chapter 7, a new figure illustrates levels of LDL receptors in people with and without familial hypercholesterolemia. Chapter 8 includes a beautiful new photo of a geyser with thermophilic bacteria in Figure 8.17, bringing to life the graphs of optimal temperatures for enzyme function. Chapter 10 discusses current research trying to genetically modify rice (a C_3 crop) so that it is capable of carrying out C_4 photosynthesis to increase yields. Chapter 11 includes a new Problem-Solving Exercise that guides students through assessing possible new treatments for bacterial infections by blocking quorum sensing. In Chapter 12, the mechanism of chromosome movement in bacteria has been updated and more cell cycle control checkpoints have been added, including one proposed by researchers in 2014.

UNIT 3 GENETICS

In Chapters 13–17, we have incorporated changes that help students grasp the more abstract concepts of genetics and their chromosomal and molecular underpinnings. For example, a new Visual Skills Question with Figure 13.6 asks students to identify where in the three life cycles haploid cells undergo mitosis, and what type of cells are formed. Chapter 14 includes new information from a 2014 genomic study on the number of genes and genetic variants contributing to height. Figure 14.15b now uses "inability to taste PTC" rather than "attached earlobe." Chapters 14 and 15 are more inclusive, clarifying the meaning of the term "normal" in genetics and explaining that sex is no longer thought to be simply binary. Other updates in Chapter 15 include new research in sex determination and a technique being developed to avoid passing on mitochondrial diseases. New Visualizing Figure 16.7 shows students various ways that DNA is illustrated. Chapter 17 has a new opening photo and story about albino donkeys to pique student interest in gene expression. To help students understand the Beadle and Tatum experiment, new Figure 17.2 explains how they obtained nutritional mutants. A new Problem-Solving Exercise asks students to identify mutations in the insulin gene and predict their effect on the protein.

Chapters 18–21 are extensively updated, driven by exciting new discoveries based on DNA sequencing and gene-editing technology. Chapter 18 has updates on histone modifications, nuclear location and the persistence of transcription factories, chromatin remodeling by ncRNAs, long noncoding RNAs (lncRNAs), the role of master regulatory genes in modifying chromatin structure, and the possible role of *p53* in the low incidence of cancer in elephants. Make Connections Figure 18.27, "Genomics, Cell Signaling, and Cancer," has been expanded to include more information on cell signaling. Chapter 19 features a new section that covers bacterial defenses against bacteriophages and describes the CRISPR-Cas9 system (Figure 19.7); updates include the Ebola, Chikungunya, and Zika viruses (Figure 19.10) and discovery of the largest virus known to date. A discussion has been added of mosquito transmission of diseases and concerns about the effects of global climate change on disease transmission. Chapter 20 has a new photo of next-generation DNA sequencing machines (Figure 20.2) and a new illustration of the widely used technique of RNA sequencing (Figure 20.13). A new section titled Editing Genes and Genomes has been added describing the **CRISPR-Cas9 system (Figure 20.14)** that has been developed to edit genes in living cells. Information has also been

Figure 20.14 Gene editing using the CRISPR-Cas9 system.

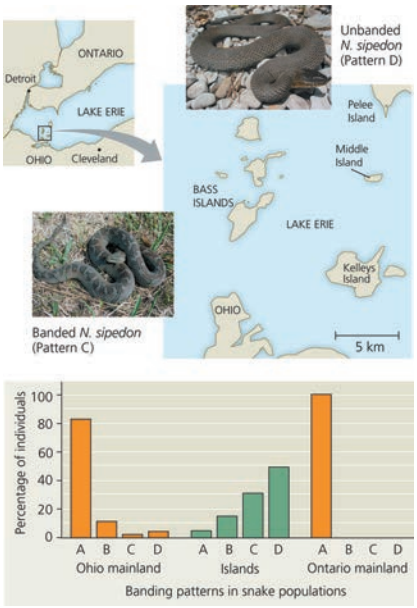


added later in the chapter on use of the CRISPR-Cas9 system, including a study in which a genetic mutation for the disease tyrosinemia was corrected in mice. Finally, the discussion of ethical considerations has been updated to include a recent report of scientists using the CRISPR-Cas9 system to edit a gene in human embryos, along with a discussion of the ethical questions raised by such experiments, such as its usage in the gene drive approach to combat carrying of diseases by mosquitoes. In Chapter 21, in addition to the usual updates of sequence-related data (speed of sequencing, number of species' genomes sequenced, etc.), there are several research updates, including some early results from the new Roadmap Epigenomics Project and results from a 2015 study focusing on 414 important yeast genes.

UNIT 4 MECHANISMS OF EVOLUTION

A major goal for this revision was to strengthen how we help students understand and interpret visual representations of evolutionary data and concepts. Toward this end, we have added a new figure (Figure 25.8), "Visualizing the Scale of Geologic Time," and a new figure **(Figure 23.12)** on **gene flow**. Several figures have been revised to improve the presentation of data, including Figure 24.6 (on reproductive isolation in mosquitofish), Figure 24.10 (on allopolyploid speciation), and Figure 25.25 (on the origin of the insect body plan). The unit also features new material that connects evolutionary concepts and societal problems. Examples include text in Chapter 22 on the 2015 discovery of teixobactin, an antibiotic that is effective against some hard-to-treat pathogens, a new discussion in Chapter 24 on the impact of climate change on hybrid zones, and a new Problem-Solving Exercise in Chapter 24 on how hybridization may have led to the spread of insecticide resistance genes in mosquitoes that transmit malaria. The unit also includes new chapter-opening stories in Chapter 22 (on a moth whose features illustrate the concepts of unity, diversity, and adaptation) and Chapter 25 (on the discovery of whale bones in the Sahara Desert). Additional changes include new text in Concept 22.3 emphasizing how populations can evolve over short periods of time, a new table (Table 23.1) highlighting the five conditions required for a population to be in Hardy-Weinberg equilibrium, and new material in Concept 25.1 describing how researchers recently succeeded for the first time in constructing a "protocell" in which replication of a template strand of RNA could occur.

Figure 23.12 Gene flow and local adaptation in the Lake Erie water snake (*Nerodia sipedon*).



UNIT 5 THE EVOLUTIONARY HISTORY OF BIOLOGICAL DIVERSITY

In keeping with our goal of improving how students interpret and create visual representations in biology, we have added a new figure (Figure 26.5, "Visualizing Phylogenetic Relationships") that introduces the visual conventions used in phylogenetic trees and helps students understand what such trees do and don't convey. Students are also provided many opportunities to practice their visual skills, with more than ten new Visual Skills Questions on topics ranging from interpreting phylogenetic trees to predicting which regions of a bacterial flagellum are hydrophobic. The unit also contains new content on tree thinking, emphasizing such key points as how sister groups provide a clear way to describe evolutionary relationships and how trees do not show a "direction" in evolution. Other major content changes include new text in Concepts 26.6, 27.4, and 28.1 on the 2015 discovery of the Lokiarchaeota, a group of archaea that may represent the sister group of the eukaryotes, new text and a new figure (Figure 26.22) on horizontal gene transfer from prokaryotes to eukaryotes, new text in Concept 27.6 describing the CRISPR-Cas9 system and a new figure (Figure 27.21) that illustrates one example of how CRISPR-Cas 9 technology has opened new avenues of research on HIV, and new material in Concept 29.3 describing how early forests contributed to global climate change (in this case, global cooling). A new Problem-Solving Exercise in Chapter 34 engages students in interpreting data from a study investigating whether frogs can acquire resistance to a fungal pathogen through controlled exposure to it. Other updates include the revision of many phylogenies to reflect recent phylogenomic data, new chapter-opening stories in Chapter 31 (on how mycorrhizae link trees of different species) and Chapter 33 (on the "blue dragon," a mollusc that preys on the highly toxic Portuguese man-of-war), new text and a new figure (Figure 34.37) on the adaptations of the kangaroo rat to its arid environment, and new material in Concept 34.7, including a new figure (Figure 34.52) describing fossil and DNA evidence indicating that humans and Neanderthals interbred, producing viable offspring. The discussion of **human evolution** also includes new text and a new figure **(Figure 34.53)** on *Homo naledi*, the most recently discovered member of the human evolutionary lineage.

Figure 34.53 Fossils of hand and foot bones of *Homo naledi*.



UNIT 6 PLANT FORM AND FUNCTION

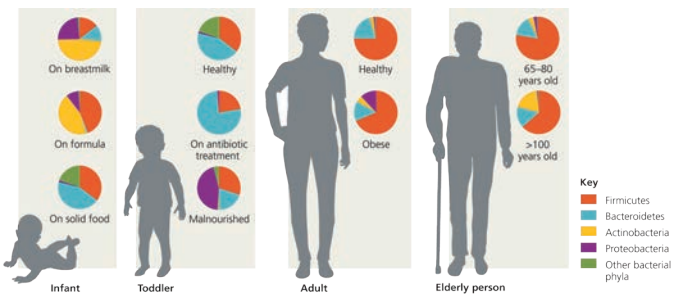
A major aim in revising Chapter 35 was to help students better understand how primary and secondary growth are related. New Visualizing Figure 35.11 enables students to picture growth at the cellular level. Also, the terms *protoderm, procambium*, and *ground meristem* have been introduced to underscore the transition of meristematic to mature tissues. A new flowchart (Figure 35.24) summarizes growth in a woody shoot. New text and a figure (Figure 35.26) focus on genome analysis of *Arabidopsis* ecotypes, relating plant morphology to ecology and evolution. In Chapter 36, new Figure 36.8 illustrates the fine branching of leaf veins, and information on

phloem-xylem water transfer has been updated. New Make Connections Figure 37.10 highlights mutualism across kingdoms and domains. Figure 37.13 and the related text include new findings on how some soil nitrogen derives from weathering of rocks. New Figure 38.3 clarifies how the terms *carpel* and *pistil* are related. The text on flower structure and the angiosperm life cycle figure identify carpels as megasporophylls and stamens as microsporophylls, correlating with the plant evolution discussion in Unit 5. In Concept 38.3, the current problem of glyphosate-resistant crops is discussed in detail. A revised Figure 39.7 helps students visualize how cells elongate. Figure 39.8 now addresses apical dominance in a Guided Tour format. Information about the role of sugars in controlling apical dominance has been added. In Concept 39.4, a new Problem-Solving Exercise highlights how global climate change affects crop productivity. Figure 39.26 on defense responses against pathogens has been simplified and improved.

UNIT 7 ANIMAL FORM AND FUNCTION

A major goal of the Unit 7 revision was to transform how students interact with and learn from representations of anatomy and physiology. For example, gastrulation is now introduced with a Visualizing Figure (Figure 47.8) that provides a clear and carefully paced introduction to three-dimensional processes that may be difficult for students to grasp. In addition, a number of the new and revised figures help students explore spatial relationships in anatomical contexts, such as the interplay of lymphatic and cardiovascular circulation (Figure 42.15) and the relationship of the limbic system to overall brain structure (Figure 49.14). A new Problem-Solving Exercise in Chapter 45 taps into student interest in medical mysteries through a case study that explores the science behind laboratory testing and diagnosis. Content updates help students appreciate the continued evolution of our understanding of even familiar phenomena, such as the sensation of thirst (Concept 44.4) and the locomotion of kangaroos and jellies (Concept 50.6). Furthermore, new text and figures introduce students to cutting-edge technology relating to such topics as RNA-based antiviral defense in invertebrates (Figure 43.4) and rapid, comprehensive characterization of viral exposure (Figure 43.24), as well as recent discoveries regarding brown fat in adult humans (Figure 40.16), the **microbiome** (Figure 41.17), parthenogenesis (Concept 46.1), and magnetoreception (Concept 50.1). As always, there is fine-tuning of pedagogy, as in discussions of the complementary roles of inactivation and voltage gating of ion channels during action potential formation (Concept 48.3) and of the experimental characterization of genetic determinants in bird migration (Figure 51.24).

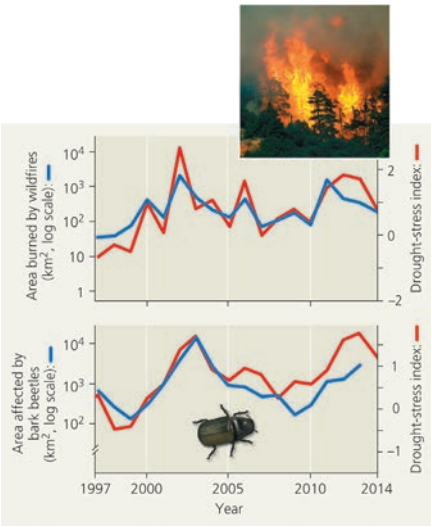
Figure 41.17 Variation in human gut microbiome at different life stages.



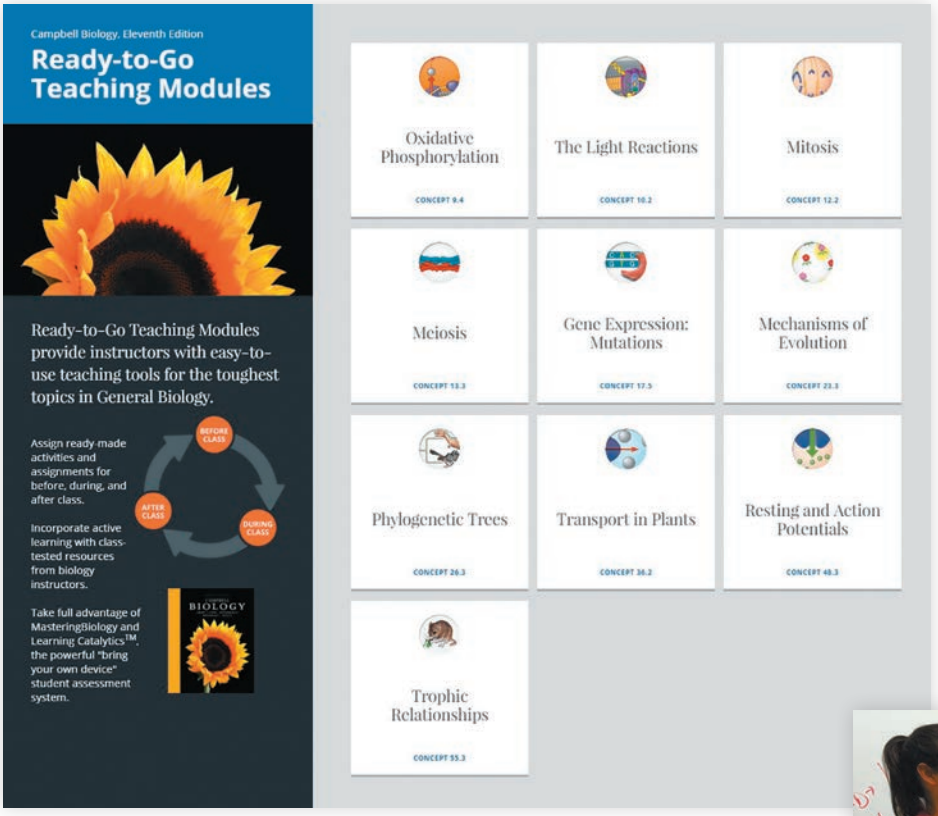
UNIT 8 ECOLOGY

The Ecology Unit has been extensively revised for the Eleventh Edition. We have reorganized and improved the conceptual framework with which students are introduced to the following core ecological topics: life tables, per capita population growth, intrinsic rate of increase ("*r*"), exponential population growth, logistic population growth, density dependence, species interactions (in particular, parasitism, commensalism, and mutualism), and MacArthur and Wilson's island biogeography model. The revision also includes a deeper integration of evolutionary principles, including a new Key Concept (52.5) and two new figures (Figures 52.22 and 52.23) on the reciprocal effects of ecology and evolution, new material in Concept 52.4 on how the geographic distributions of species are shaped by a combination of evolutionary history and ecological factors, and five new Make Connections Questions that ask students to examine how ecological and evolutionary mechanisms interact. In keeping with our goal of expanding and strengthening our coverage of climate change, we have added a new discussion and a new figure (Figure 52.20) on how climate change has affected the distribution of a keystone species, a new section of text in Concept 55.2 on how climate change affects NPP, a new figure (Figure 55.8) on how **climate change** has caused an increase in wildfires and insect outbreaks, a new Problem-Solving Exercise in Chapter 55 that explores how insect outbreaks induced by climate change can cause an ecosystem to switch from a carbon sink to a carbon source, a new figure (Figure 56.29) on the greenhouse effect, new text in Concept 56.4 on biological effects of climate change, and a new Make Connections Figure (Figure 56.30) on how climate change affects all levels of biological organization. Additional updates include a new figure (Figure 53.25) on per capita ecological footprints, a new chapter-opening story in Chapter 54 on a seemingly unlikely mutualism between a shrimp and a much larger predatory fish, new text in Concept 54.1 emphasizing that each partner in a mutualism experiences both benefits and costs, new text in Concept 54.1 describing how the outcome of an ecological interaction can change over time, two new figures (Figures 54.29 and 54.30) on the island equilibrium model, a new figure (Figure 54.31) documenting two shrew species as unexpected hosts of the Lyme disease, new text in Concept 56.1 comparing extinction rates today with those typically seen in the fossil record, and a new discussion and figure (Figure 56.22) on the restoration of a degraded urban stream.

Figure 55.8 Climate change, wildfires, and insect outbreaks.



NEW! Ready-to-Go Teaching Modules help instructors efficiently make use of the best teaching tools before, during, and after class.

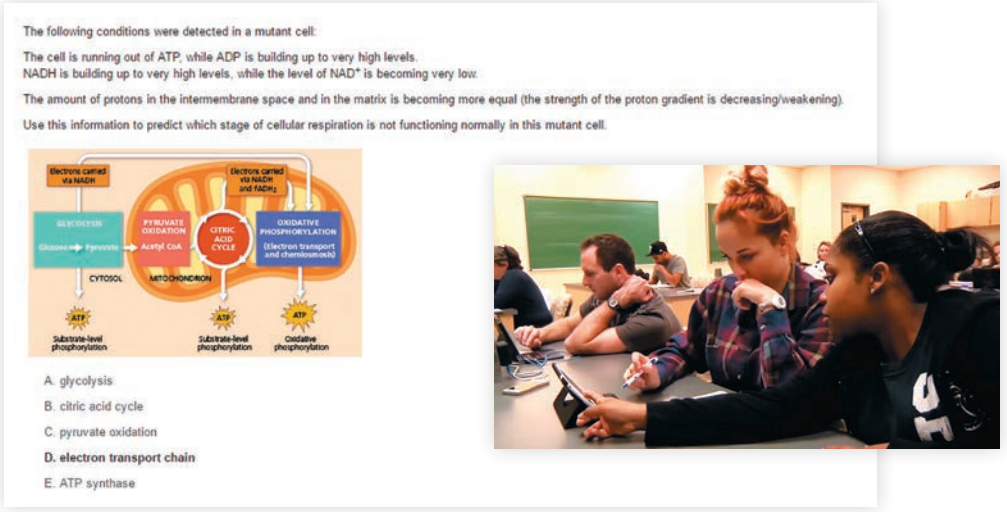


The **Ready-to-Go Teaching Modules** incorporate the best that the text, MasteringBiology, and Learning Catalytics have to offer, along with new ideas for in-class activities. The modules can be accessed through the Instructor Resources area of MasteringBiology.

Instructors can easily incorporate **active learning** into their courses using suggested activity ideas and questions. Videos demonstrate how the activities can be used in class.



Learning Catalytics™ allows students to use their smartphone, tablet, or laptop to respond to questions in class. Visit learningcatalytics.com.



Each chapter is organized around a framework of 3 to 7 **Key Concepts** that focus on the big picture and provide a context for supporting details.

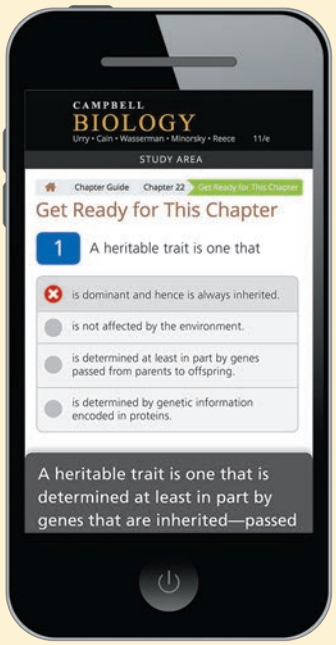
Every chapter opens with a visually dynamic **photo** accompanied by an **intriguing question** that invites students into the chapter.

The **List of Key Concepts** introduces the big ideas covered in the chapter.



Get Ready for This Chapter

NEW! Get Ready for This Chapter questions provide a quick check of students' knowledge of basic information needed to learn the new content of a chapter, with feedback.



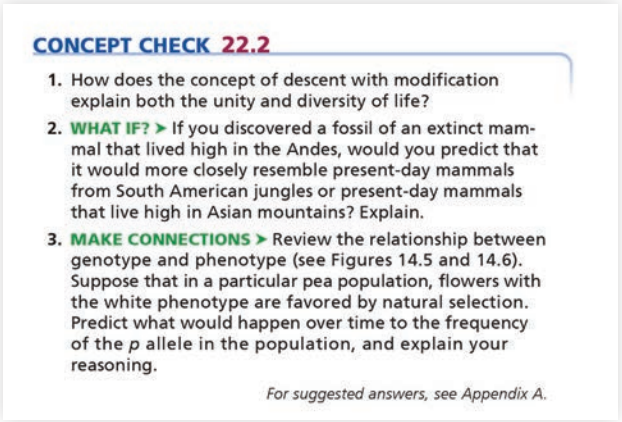
These questions are available as MasteringBiology assignments and as self-study quizzes in the Study Area.

After reading a Key Concept section, students can check their understanding using the **Concept Check Questions.**

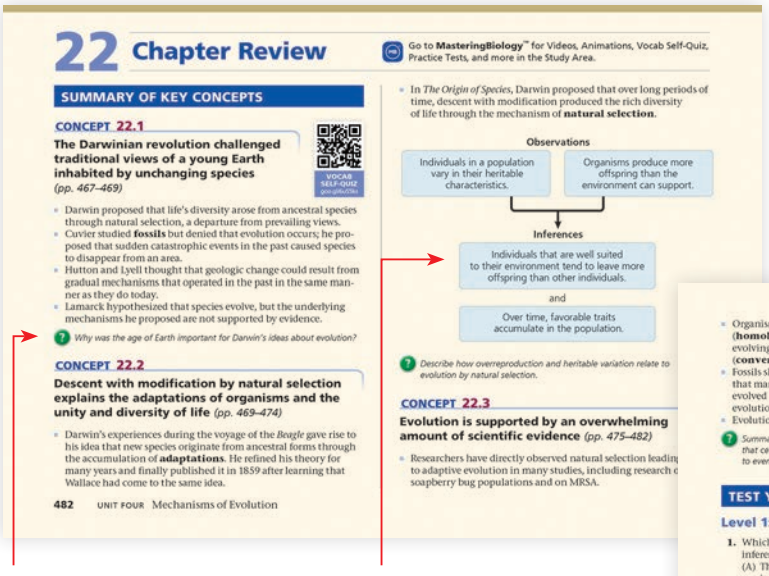
Questions throughout the chapter encourage students to **read the text actively.**

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

Make Connections Questions ask students to relate content in the chapter to material presented earlier in the course.



The **Summary of Key Concepts** refocuses students on the main points of the chapter.



22 Chapter Review

Go to MasteringBiology™ for Videos, Animations, Vocab Self-Quiz, Practice Tests, and more in the Study Area.

SUMMARY OF KEY CONCEPTS

CONCEPT 22.1

The Darwinian revolution challenged traditional views of a young Earth inhabited by unchanging species *(pp. 467–469)*

- Darwin proposed that life's diversity arose from ancestral species through natural selection, a departure from prevailing views.
- Cuvier studied **fossils** but denied that evolution occurs; he proposed that sudden catastrophic events in the past caused species to disappear from an area.
- Hutton and Lyell thought that geologic change could result from gradual mechanisms that operated in the past in the same manner as they do today.
- Lamarck hypothesized that species evolve, but the underlying mechanisms he proposed are not supported by evidence.

? *Why was the age of Earth important for Darwin's ideas about evolution?*

CONCEPT 22.2

Descent with modification by natural selection explains the adaptations of organisms and the unity and diversity of life *(pp. 469–474)*

- Darwin's experiences during the voyage of the *Beagle* gave rise to his idea that new species originate from ancestral forms through the accumulation of **adaptations**. He refined his theory for many years and finally published it in 1859 after learning that Wallace had come to the same idea.

482 UNIT FOUR Mechanisms of Evolution

- In *The Origin of Species*, Darwin proposed that over long periods of time, descent with modification produced the rich diversity of life through the mechanism of **natural selection**.

Observations

Individuals in a population vary in their heritable characteristics.

Organisms produce more offspring than the environment can support.

Inferences

Individuals that are well suited to their environment tend to leave more offspring than other individuals.

and

Over time, favorable traits accumulate in the population.

? *Describe how overreproduction and heritable variation relate to evolution by natural selection.*

CONCEPT 22.3

Evolution is supported by an overwhelming amount of scientific evidence *(pp. 475–482)*

- Researchers have directly observed natural selection leading to adaptive evolution in many studies, including research on soapberry bug populations and on MRSA.

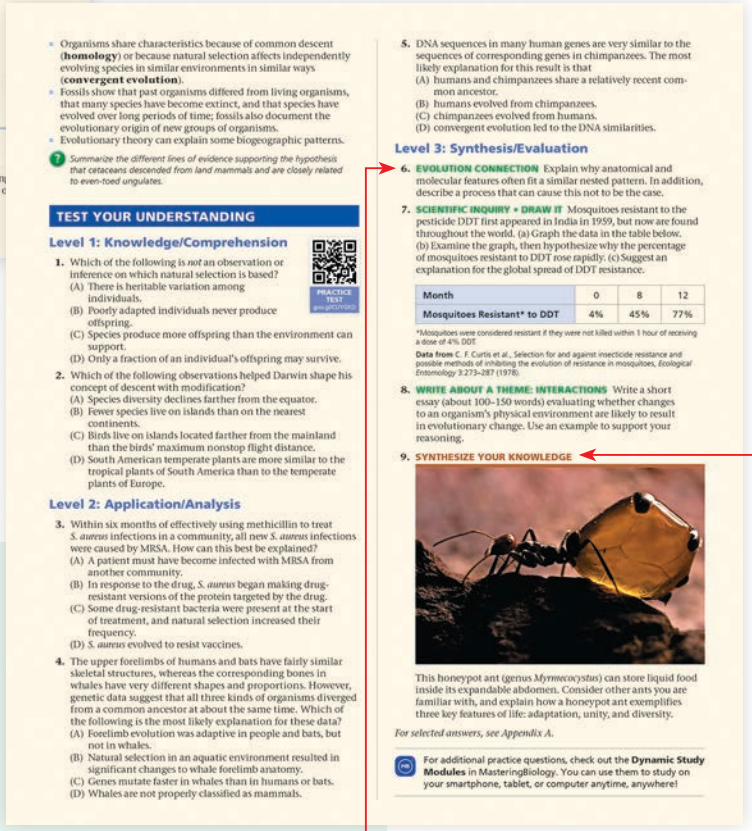
VOCAB SELF-QUIZ goo.gl/6u55ks

PRACTICE TEST goo.gl/CUYGKD

NEW! QR codes and URLs at the end of every chapter give students quick access to **Vocabulary Self-Quizzes** and **Practice Tests** on their smartphones, tablets, and computers.

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

Summary Figures recap key information visually.



- Organisms share characteristics because of common descent (**homology**) or because natural selection affects independently evolving species in similar environments in similar ways (**convergent evolution**).
- Fossils show that past organisms differed from living organisms, that many species have become extinct, and that species have evolved over long periods of time; fossils also document the evolutionary origin of new groups of organisms.
- Evolutionary theory can explain some biogeographic patterns.

? *Summarize the different lines of evidence supporting the hypothesis that cetaceans descended from land mammals and are closely related to even-toed ungulates.*

TEST YOUR UNDERSTANDING

Level 1: Knowledge/Comprehension

1. Which of the following is *not* an observation or inference on which natural selection is based?
(A) There is heritable variation among individuals.
(B) Poorly adapted individuals never produce offspring.
(C) Species produce more offspring than the environment can support.
(D) Only a fraction of an individual's offspring may survive.
2. Which of the following observations helped Darwin shape his concept of descent with modification?
(A) Species diversity declines farther from the equator.
(B) Fewer species live on islands than on the nearest continents.
(C) Birds live on islands located farther from the mainland than the birds' maximum nonstop flight distance.
(D) South American temperate plants are more similar to the tropical plants of South America than to the temperate plants of Europe.

Level 2: Application/Analysis

3. Within six months of effectively using methicillin to treat *S. aureus* infections in a community, all new *S. aureus* infections were caused by MRSA. How can this best be explained?
(A) A patient must have become infected with MRSA from another community.
(B) In response to the drug, *S. aureus* began making drug-resistant versions of the protein targeted by the drug.
(C) Some drug-resistant bacteria were present at the start of treatment, and natural selection increased their frequency.
(D) *S. aureus* evolved to resist vaccines.
4. The upper forelimbs of humans and bats have fairly similar skeletal structures, whereas the corresponding bones in whales have very different shapes and proportions. However, genetic data suggest that all three kinds of organisms diverged from a common ancestor at about the same time. Which of the following is the most likely explanation for these data?
(A) Forelimb evolution was adaptive in people and bats, but not in whales.
(B) Natural selection in an aquatic environment resulted in significant changes to whale forelimb anatomy.
(C) Genes mutate faster in whales than in humans or bats.
(D) Whales are not properly classified as mammals.
5. DNA sequences in many human genes are very similar to the sequences of corresponding genes in chimpanzees. The most likely explanation for this result is that
(A) humans and chimpanzees share a relatively recent common ancestor.
(B) humans evolved from chimpanzees.
(C) chimpanzees evolved from humans.
(D) convergent evolution led to the DNA similarities.

Level 3: Synthesis/Evaluation

6. **EVOLUTION CONNECTION** Explain why anatomical and molecular features often fit a similar nested pattern. In addition, describe a process that can cause this not to be the case.
7. **SCIENTIFIC INQUIRY • DRAW IT** Mosquitoes resistant to the pesticide DDT first appeared in India in 1959, but now are found throughout the world. (a) Graph the data in the table below. (b) Examine the graph, then hypothesize why the percentage of mosquitoes resistant to DDT rose rapidly. (c) Suggest an explanation for the global spread of DDT resistance.

Month	0	8	12
Mosquitoes Resistant* to DDT	4%	45%	77%

*Mosquitoes were considered resistant if they were not killed within 1 hour of receiving a dose of 4% DDT.

Data from C. F. Curtis et al., Selection for and against insecticide resistance and possible methods of inhibiting the evolution of resistance in mosquitoes, *Ecological Entomology* 3:273–287 (1978).

8. **WRITE ABOUT A THEME: INTERACTIONS** Write a short essay (about 100–150 words) evaluating whether changes to an organism's physical environment are likely to result in evolutionary change. Use an example to support your reasoning.
9. **SYNTHESIZE YOUR KNOWLEDGE**

This honeypot ant (genus *Myrmecocystus*) can store liquid food inside its expandable abdomen. Consider other ants you are familiar with, and explain how a honeypot ant exemplifies three key features of life: adaptation, unity, and diversity.

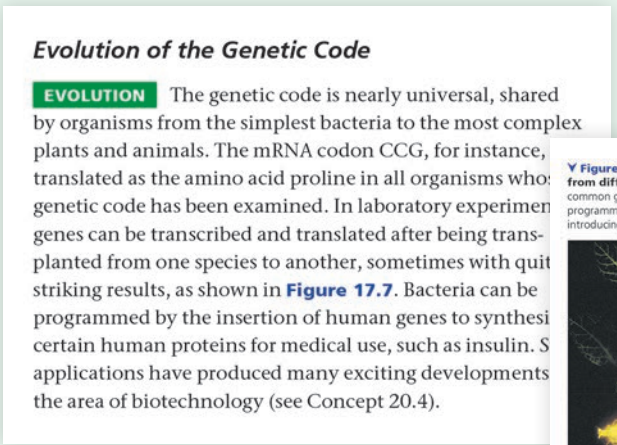
For selected answers, see Appendix A.

For additional practice questions, check out the **Dynamic Study Modules** in MasteringBiology. You can use them to study on your smartphone, tablet, or computer anytime, anywhere!

Evolution Connection Questions are included in every Chapter Review.

Synthesize Your Knowledge Questions ask students to apply their understanding of the chapter content to explain an intriguing photo.

Evolution, the fundamental theme of biology, is emphasized throughout. Every chapter has a section explicitly relating the chapter content to evolution:



Evolution of the Genetic Code

EVOLUTION The genetic code is nearly universal, shared by organisms from the simplest bacteria to the most complex plants and animals. The mRNA codon CCG, for instance, translated as the amino acid proline in all organisms whos genetic code has been examined. In laboratory experimen genes can be transcribed and translated after being trans-planted from one species to another, sometimes with quit striking results, as shown in **Figure 17.7**. Bacteria can be programmed by the insertion of human genes to synthesi certain human proteins for medical use, such as insulin. S applications have produced many exciting developments the area of biotechnology (see Concept 20.4).

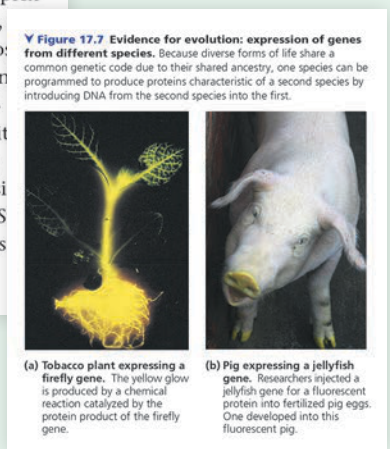
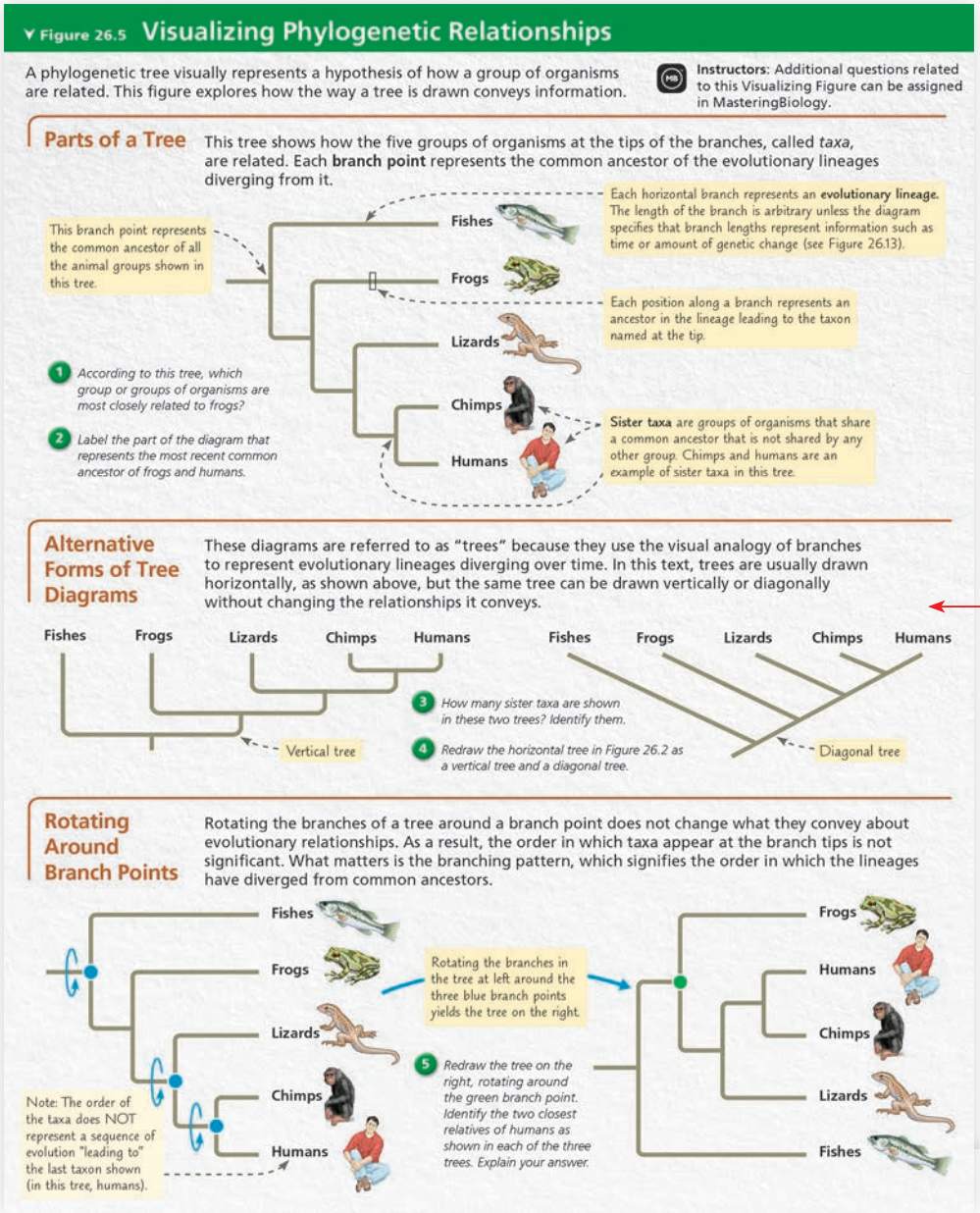


Figure 17.7 Evidence for evolution: expression of genes from different species. Because diverse forms of life share a common genetic code due to their shared ancestry, one species can be programmed to produce proteins characteristic of a second species by introducing DNA from the second species into the first.

(a) **Tobacco plant expressing a firefly gene.** The yellow glow is produced by a chemical reaction catalyzed by the protein product of the firefly gene.

(b) **Pig expressing a jellyfish gene.** Researchers injected a jellyfish gene for a fluorescent protein into fertilized pig eggs. One developed into this fluorescent pig.

NEW! Visualizing Figures teach students how to interpret diagrams and models in biology. Embedded questions give students practice applying visual skills as they read the figure.



▼ Figure 26.5 Visualizing Phylogenetic Relationships

A phylogenetic tree visually represents a hypothesis of how a group of organisms are related. This figure explores how the way a tree is drawn conveys information.

Instructors: Additional questions related to this Visualizing Figure can be assigned in MasteringBiology.

Parts of a Tree

This tree shows how the five groups of organisms at the tips of the branches, called *taxa*, are related. Each **branch point** represents the common ancestor of the evolutionary lineages diverging from it.

This branch point represents the common ancestor of all the animal groups shown in this tree.

Each horizontal branch represents an **evolutionary lineage.** The length of the branch is arbitrary unless the diagram specifies that branch lengths represent information such as time or amount of genetic change (see Figure 26.13).

Each position along a branch represents an ancestor in the lineage leading to the taxon named at the tip.

Fishes, Frogs, Lizards, Chimps, Humans

Sister taxa are groups of organisms that share a common ancestor that is not shared by any other group. Chimps and humans are an example of sister taxa in this tree.

1 *According to this tree, which group or groups of organisms are most closely related to frogs?*

2 *Label the part of the diagram that represents the most recent common ancestor of frogs and humans.*

Alternative Forms of Tree Diagrams

These diagrams are referred to as "trees" because they use the visual analogy of branches to represent evolutionary lineages diverging over time. In this text, trees are usually drawn horizontally, as shown above, but the same tree can be drawn vertically or diagonally without changing the relationships it conveys.

Fishes Frogs Lizards Chimps Humans

Vertical tree

Fishes Frogs Lizards Chimps Humans

Diagonal tree

3 *How many sister taxa are shown in these two trees? Identify them.*

4 *Redraw the horizontal tree in Figure 26.2 as a vertical tree and a diagonal tree.*

Rotating Around Branch Points

Rotating the branches of a tree around a branch point does not change what they convey about evolutionary relationships. As a result, the order in which taxa appear at the branch tips is not significant. What matters is the branching pattern, which signifies the order in which the lineages have diverged from common ancestors.

Fishes, Frogs, Lizards, Chimps, Humans

Note: The order of the taxa does NOT represent a sequence of evolution "leading to" the last taxon shown (in this tree, humans).

Rotating the branches in the tree at left around the three blue branch points yields the tree on the right.

5 *Redraw the tree on the right, rotating around the green branch point. Identify the two closest relatives of humans as shown in each of the three trees. Explain your answer.*

Frogs, Humans, Chimps, Lizards, Fishes

For more practice, each Visualizing Figure is accompanied by an automatically graded assignment in MasteringBiology with feedback for students.

Visualizing Figures include:

Figure 5.16 Visualizing Proteins, *p. 79*

Figure 6.32 Visualizing the Scale of the Molecular Machinery in a Cell, *pp. 122-123*

Figure 16.7 Visualizing DNA, *p. 319*

Figure 25.8 Visualizing the Scale of Geologic Time, *pp. 530-531*

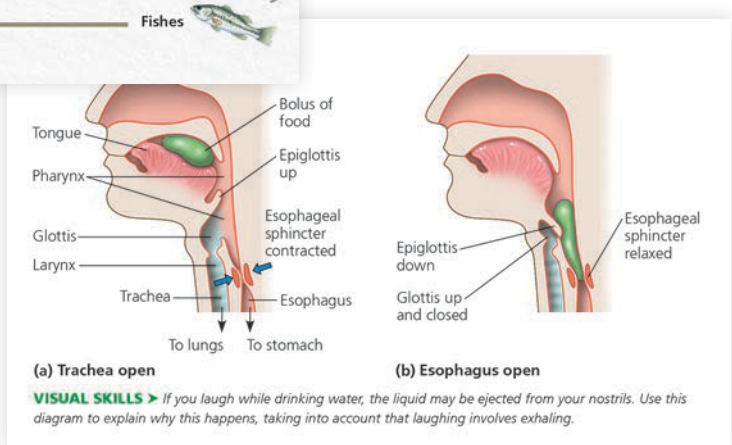
Figure 26.5 Visualizing Phylogenetic Relationships, *shown at left and on p. 554*

Figure 35.11 Visualizing Primary and Secondary Growth, *p. 765*

Figure 47.8 Visualizing Gastrulation, *p. 1048*

Figure 55.13 Visualizing Biogeochemical Cycles, *p. 1247*

NEW! Visual Skills Questions give students practice interpreting illustrations and photos in the text.



VISUAL SKILLS ➤ *If you laugh while drinking water, the liquid may be ejected from your nostrils. Use this diagram to explain why this happens, taking into account that laughing involves exhaling.*