ELEVENTH EDITION

CAMPBELL BIOLOGY

Australian and New Zealand Version

URRY • MEYERS • CAIN
WASSERMAN • MINORSKY • REECE

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Australian and New Zealand Version

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Printed in China

1 2 3 4 5 22 21 20 19 18

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Pearson Australia Group Pty Ltd ABN 40 004 245 943

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707 Collins Street
Melbourne VIC 3008

www.pearson.com.au

Authorised adaptation from the United States edition, entitled CAMPBELL BIOLOGY, 11th Edition, ISBN: 0134093410 by URRY, LISA A.; CAIN, MICHAEL L.; WASSERMAN, STEVEN A.; MINORSKY, PETER V.; REECE, JANE B., published by Pearson Education Inc, Copyright © 2017.

Eleventh adaptation edition published by Pearson Australia Group Pty Ltd, Copyright © 2018

National Library of Australia Cataloguing-in-Publication entry
Creator: Urry, Lisa A., author.
Title: Campbell biology / Lisa A. Urry [and six] others.
Edition: 11th edition.
ISBN: 9781488613715 (hardback)
ISBN: 9781488613739 (eBook)
Notes: Other authors: Noel Meyers; Michael L. Cain; Steven A. Wasserman; Peter V. Minorsky; Jane B. Reece; Neil A. Campbell.
Includes index.
Subjects: Biology.
Biology—Problems, exercises, etc.
Biology—Textbooks.

Credits continue following the appendices.

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Brief Contents

About the Authors

Lisa A. Urry is Professor of Biology and Chair of the Biology Department at Mills College. After earning a BA at Tufts University, she completed her PhD at the Massachusetts Institute of Technology (MIT). Lisa has conducted research on gene expression during embryonic and larval development in sea urchins. Deeply committed to promoting opportunities in science for women and underrepresented minorities, she has taught courses ranging from introductory and developmental biology to a nonmajors course called Evolution for Future Presidents. Lisa is a coauthor of *Campbell Biology in Focus*.

Noel Meyers completed his PhD in plant pollination biology at the University of Queensland. With the CSIRO Division of Plant Industry he has completed two post-doctoral research fellowships. For his teaching Noel won an Australian Award for University Teaching and a Pearson Uniserve Award for his contributions to science students' learning. He has also earned a Fellowship of the Higher Education Research and Development Society of Australasia (FHERDSA). Noel dedicates his life to science education.

Michael L. Cain is an ecologist and evolutionary biologist who is now writing full-time. Michael earned an AB from Bowdoin College, an MSc from Brown University, and a PhD from Cornell University. As a faculty member at New Mexico State University, he taught introductory biology, ecology, evolution, botany, and conservation biology. Michael is the author of dozens of scientific papers on topics that include foraging behaviour in insects and plants, long-distance seed dispersal, and speciation in crickets. He is a coauthor of *Campbell Biology in Focus* and of an ecology textbook.

Steven A. Wasserman is Professor of Biology at the University of California, San Diego (UCSD). He earned an AB from Harvard University and a PhD from MIT. Working on the fruit fly *Drosophila*, Steve has undertaken research on developmental biology, reproduction, and immunity. Having taught genetics, development, and physiology to undergraduate, graduate, and medical students, he now focuses on introductory biology, for which he has been honoured with UCSD's Distinguished Teaching Award. He is a coauthor of *Campbell Biology in Focus*.

Peter V. Minorsky is Professor of Biology at Mercy College in New York, where he teaches introductory biology, ecology, and botany. He received his AB from Vassar College and his PhD from Cornell University. Peter has taught at Kenyon College, Union College, Western Connecticut State University, and Vassar College; he is also the science writer for the journal *Plant Physiology*. His research interests concern how plants sense environmental change. Peter received the 2008 Award for Teaching Excellence at Mercy College and is a coauthor of *Campbell Biology in Focus*.

Jane B. Reece, the head of the author team for Editions 8–10 of *Campbell Biology*, was Neil Campbell's longtime collaborator. Jane taught biology at Middlesex County College and Queensborough Community College. She holds an AB from Harvard University, an MS from Rutgers University, and a PhD from the University of California, Berkeley. Jane's research as a doctoral student at UC Berkeley and postdoctoral fellow at Stanford University focused on genetic recombination in bacteria. Besides her work on *Campbell Biology*, Jane has been a coauthor on all the *Campbell* texts.

Neil A. Campbell (1946–2004) earned his MA from the University of California, Los Angeles, and his PhD from the University of California, Riverside. His research focused on desert and coastal plants. Neil's 30 years of teaching included introductory biology courses at Cornell University, Pomona College, and San Bernardino Valley College, where he received the college's first Outstanding Professor Award in 1986. For many years he was also a visiting scholar at UC Riverside. Neil was the founding author of *Campbell Biology*.

Pearson Australia and the author gratefully acknowledge the following contributors for providing Australian/New Zealand content.

Bernard N. Cooke graduated as a teacher. He took up roles as discipline leader of science in several schools. He then trained teachers, before working as an academic. Bernie is well known for his work on kangaroo behaviour, and for his work on the famed fangaroo—the fossilised remains of a carnivorous kangaroo.

David McKay has 30 years' experience in teaching and research and has received several awards for excellence in university teaching and administration including a national award for his work on transition and enabling programs. David has degrees at the bachelor, masters and PhD levels in biochemistry and molecular biology and has published more than 30 papers in these areas as well as writing two introductory texts on molecular biology.

Alwyn Grenfell has more than 40 years' experience in teaching and research in the natural sciences, particularly the environmental and earth sciences. He holds a BSc degree with first-class honours and a PhD in science as well as formal qualifications in education. Alwyn's strong commitment to encouraging and improving learning by science students is reflected in his leadership of a number of projects that have been successful in making science more accessible and engaging for students.

Preface

From Noel Meyers

Within the pages of this book, you will find the distilled wisdom of all the biologists who have gone before you. If 50 years ago you had known the contents of this book, you would have been revered as a genius. Others would have said your mind was a once-in-a-generation gift. Now, you are learning the materials in your first year of university—such have been the advancements in knowledge. Times change, knowledge builds and so will yours.

In this book, we have shaped a story built on the classical themes and case studies. We lead you down the pathway that your forebears walked before you, in their quest to understand the biological world. We have gone further though. We highlight the unique nature and history of life in the Southern Hemisphere, with its radically different solutions to survival. We convey to you the notions of deep time that shaped Australia's and New Zealand's biological legacy.

Our biological understandings of tomorrow will arise through your work and that of others. I know that you will work to share a world with future generations better understood, better nurtured and more appreciated than the one we entrust to you.

From the US Author Team

We are honoured 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 xxx–xxxiii), 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 **practise 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 xii–xix for more information and examples.

- **Visualising Figures** and **Visual Skills Questions** give students practice in interpreting and creating visual representations in biology. The Visualising 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**. The new online learning tools include:
  - **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**.
  - **Animations and videos** that bring biology to life. These include resources from **HHMI BioInteractive** that engage students in topics from the discovery of the double helix to evolution.
- The impact of **climate change** at all levels of the biological hierarchy is explored throughout the text, starting with a new photo (Figure 1.12) and discussion in Chapter 1 and concluding with a new Make Connections Figure (Figure 56.31) 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 summarised on pages. xii–xix, 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 organising 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. Chief among the themes of *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 organised 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 Visualising Figures, our popular Exploring Figures and Make Connections Figures epitomise 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 compartmentalise 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, Synthesise 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 practise scientific thinking, along with the Problem-Solving Exercises, Scientific Skills Exercises, and Interpret the Data Questions.

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 Figure Walkthroughs, Problem-Solving Exercises, and Visualising Tutorials**, 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, 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 xxi–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 pages xx–xxiv). 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 email 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:

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Highlights of New Content

This section highlights selected new content and pedagogical changes in *CAMPBELL BIOLOGY*, Eleventh Edition.

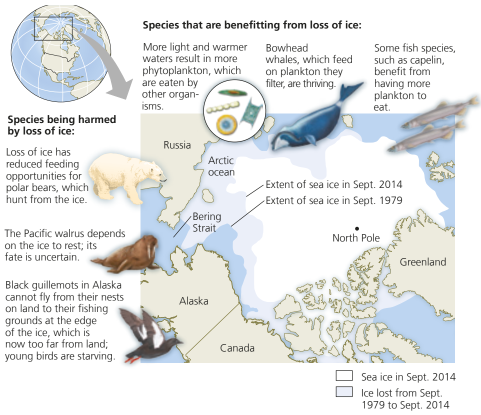
CHAPTER 1 Evolution, the Themes of Biology, and Scientific Inquiry

Chapter 1 introduces Australia's western pygmy possum, and the kind of suspended animation (torpor) it uses to wait out poor weather. 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** and impacts on Antarctica. Chapter 5 has updates on lactose intolerance, *trans* fats, the effects of diet on blood cholesterol, protein sequences and structures, and intrinsically disordered proteins. Students learn about exoplanets and recent potential evidence for life on Mars. 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

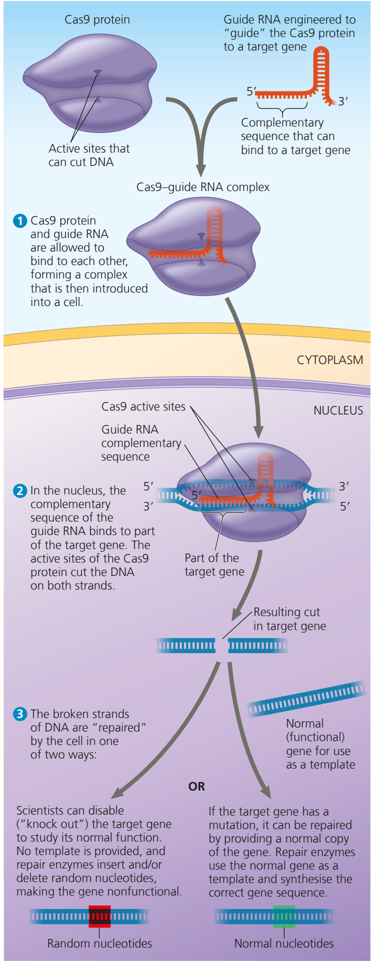
Our main goal for this unit was to enhance accessibility for students. New Visualising Figure 6.32 shows the profusion of molecules and structures in a cell, all drawn to scale. In Chapter 7, a new figure illustrates levels of LDL receptors in people with and without familial hypercholesterolaemia. Chapter 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.

UNIT 3 GENETICS

In Chapters 13–17, we have incorporated changes that help students to 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 Visualising 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 remodelling 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. Chapter 19 features a new section that covers bacterial defences 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

Figure 20.14 Gene editing using the CRISPR-Cas9 system.

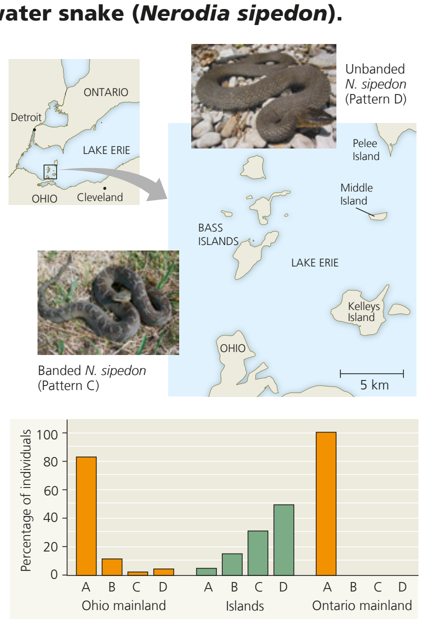


been developed to edit genes in living cells. Finally, the discussion of ethical considerations has been updated to include a recent report of scientists using the CRISPR-Cas9 system to edit a gene in human embryos, along with a discussion of the ethical questions raised by such experiments, such as 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. Towards this end, we have added a new figure (Figure 25.8), "Visualising the Scale of Geological Time," and a new figure **(Figure 23.13)** 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 25.36 (on the origin of the insect body plan). The unit also features new material that describes the Ediacaran fauna and early life on Earth that we know from Australian fossil materials, 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 hybridisation 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 emphasising 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 Chapter 25 introducing the newly discovered continent of Zealandia, and the implications it holds for New Zealand biota.

Figure 23.13 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, "Visualising 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 practise 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, emphasising 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, 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 34.36) on the adaptations of the kangaroo rat to its arid environment, and new material in Concept 34.7, including a new figure (Figure 34.51) 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*.

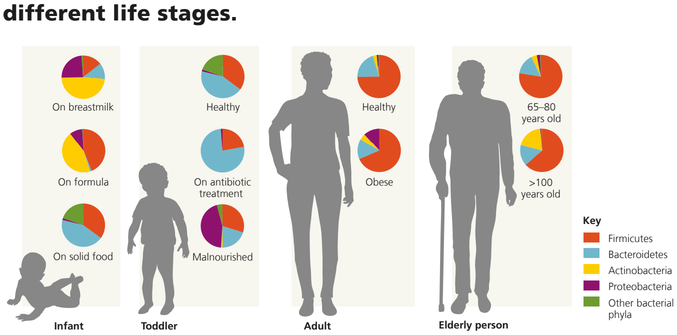
UNIT 6 PLANT FORM AND FUNCTION

A major aim in revising Chapter 35 was to help students better understand how primary and secondary growth are related. New Visualising Figure 35.12 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) summarises 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 37.14 highlights mutualism across kingdoms and domains. Concept 37.1 expands considerations of Australian and New Zealand soils, and introduces some unique adaptations plants use to survive Australia's old and nutrient-poor soils. 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. A revised Figure 39.7 helps students visualise 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 defence 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 Visualising 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 jellyfish (Concept 50.6). Furthermore, new text and figures introduce students to cutting-edge technology relating to such topics as RNA-based antiviral defence in invertebrates (Figure 43.4) and rapid, comprehensive characterisation 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). In Concept 46.2, we have expanded and clarified differences in the reproductive systems of placental and marsupial mammals. The groups have evolved in response to Australia's drying climate in the last tens of millions of years.

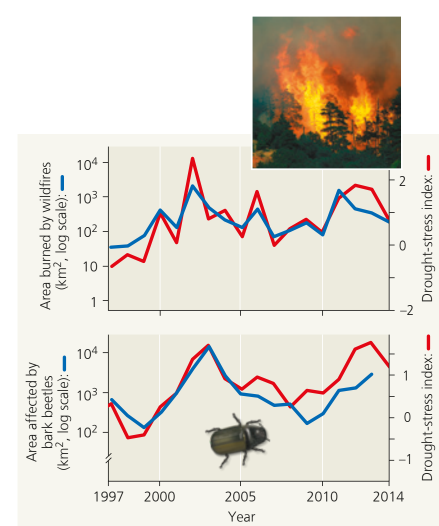
Figure 41.17 Variation in human gut microbiome at different life stages.



UNIT 8 ECOLOGY

The Ecology Unit has been extensively revised for the Eleventh Edition. We have reorganised 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 52.23 and 52.24) 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 52.19) 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 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 56.30) on the greenhouse effect and new text in Concept 56.4 on biological effects of climate change. In addition, a new Make Connections Figure (Figure 56.31) on how climate change affects all levels of biological organisation includes work from a group of University of Queensland Researchers who have identified what may be the first recorded extinction due to climate change: the Bramble Cay melomys. 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 emphasising 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 54.31 and 54.33) on the island equilibrium model, a new figure (Figure 54.34) documenting two shrew species as unexpected hosts of 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 56.23) on the restoration of a degraded urban stream.

Figure 55.8 Climate change, wildfires, and insect outbreaks.



Ready-to-Go Teaching Modules for Instructors

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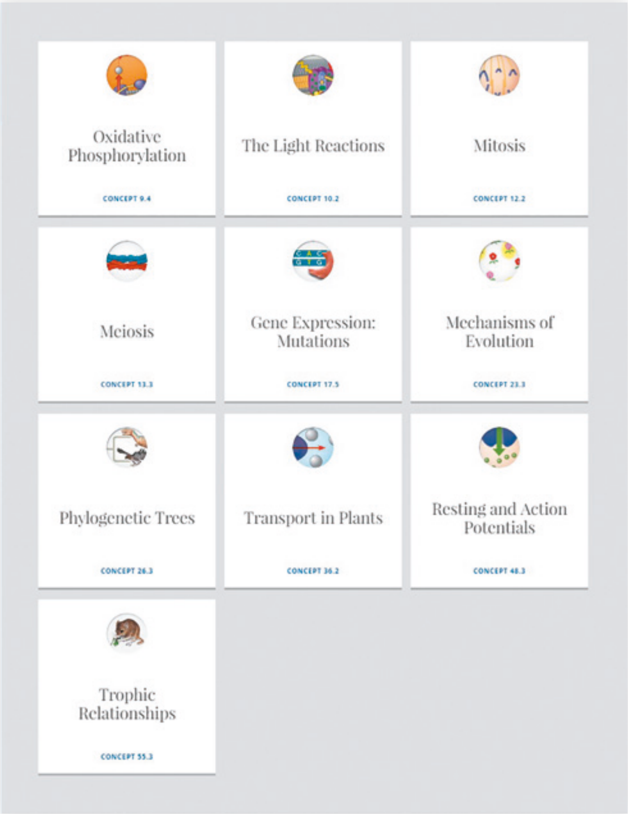
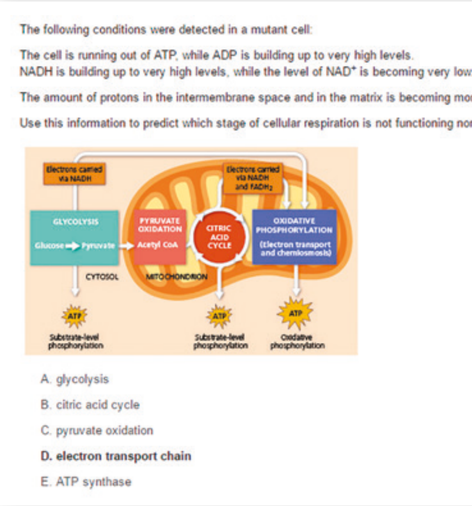


The **Ready-to-Go Teaching Modules** incorporate the best that the text, MasteringBiology, and Learning Catalytics have to offer, along with new ideas for in-class activities. The modules can be accessed through the Instructor Resources area of MasteringBiology.

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


The following conditions were detected in a mutant cell:

The cell is running out of ATP, while ADP is building up to very high levels.
NADH is building up to very high levels, while the level of NAD⁺ is becoming very low.

The amount of protons in the intermembrane space and in the matrix is becoming more equal (the strength of the proton gradient is decreasing/weakening).

Use this information to predict which stage of cellular respiration is not functioning normally in this mutant cell.

A. glycolysis
B. citric acid cycle
C. pyruvate oxidation
D. electron transport chain
E. ATP synthase

See the Big Picture

Each chapter is organised around a framework of three to seven **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.

Figure 27.1 Why is this lake's water pink?

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

KEY CONCEPTS

27.1 Structural and functional adaptations contribute to prokaryotic success

27.2 Rapid reproduction, mutation, and genetic recombination promote genetic diversity in prokaryotes

27.3 Diverse nutritional and metabolic adaptations have evolved in prokaryotes

27.4 Prokaryotes have radiated into a diverse set of lineages

27.5 Prokaryotes play crucial roles in the biosphere

27.6 Prokaryotes have both beneficial and harmful impacts on humans

Masters of Adaptation

After heavy summer rains, Australia's hyper-saline lakes appear pink (**Figure 27.1**). If you poured a cup of water from this lake onto your skin, you would receive third-degree burns. You would burn because salt concentrations in hyper-saline lakes can reach 37% (about 10 times greater than seawater). Lakes Eyre, Torrens, and Gairdner represent some of Australia's largest hyper-saline lakes, covering more than 25,000 km^2. When the water evaporates into the tinder-dry air, little remains except salt pans. Burning waters, or frying salt pans, provide some of the harshest environments for life. Yet, in the pinkish waters, life abounds.

The pink colour of Hutt Lagoon in Western Australia (Figure 27.1) comes from trillions of prokaryotes in the domains Archaea and Bacteria, including archaea in the genus *Halobacterium*. These archaea have red membrane pigments (carotenoids), some of which capture light energy that is used to drive ATP synthesis. *Halobacterium* species are among the most salt-tolerant organisms on Earth; they thrive in salinities that dehydrate and kill other cells. A *Halobacterium* cell compensates for water lost through osmosis by pumping potassium ions (K^+) into the cell until the ionic concentration inside the cell matches the concentration outside.

Like *Halobacterium*, many other prokaryotes can tolerate extreme conditions.

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.

CONCEPT CHECK 22.2

1. How does the concept of descent with modification explain both the unity and diversity of life?
2. **WHAT IF?** ➤ If you discovered a fossil of an extinct reptile that lived high in New Zealand's Southern Alps, would you predict that it would more closely resemble present-day reptiles from lowland New Zealand forests or present-day reptiles that live high in European mountains? Explain.
3. **MAKE CONNECTIONS** ➤ Review the relationship between genotype and phenotype (see Figures 14.5 and 14.6). Suppose that in a particular pea population, flowers with the white phenotype are favoured by natural selection. Predict what would happen over time to the frequency of the *p* allele in the population, and explain your reasoning.

For suggested answers, see Appendix A.

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

22 Chapter Review

SUMMARY OF KEY CONCEPTS

CONCEPT 22.1

The Darwinian revolution challenged traditional views of a young Earth inhabited by unchanging species *(pp. 469–471)*

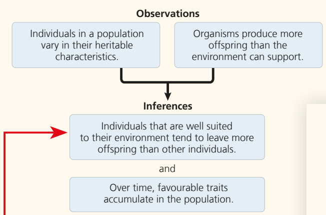
- Darwin proposed that life's diversity arose from ancestral species through natural selection, a departure from prevailing views.
- Cuvier studied **fossils** but denied that evolution occurs; he proposed that sudden catastrophic events in the past caused species to disappear from an area.
- Hutton and Lyell thought that geological change could result from gradual mechanisms that operated in the past in the same manner as they do today.
- Lamarck hypothesised 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. 471–476)*

- 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.
- 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**.



? *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. 477–484)*

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

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 biogeographical patterns.

? *Summarise 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 further from the equator.
(B) Fewer species live on islands than on the nearest continents.
(C) Birds live on islands located further from the mainland than the birds' maximum nonstop flight distance.
(D) Australian temperate plants are more similar to Australian tropical plants 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 hypothesise why the percentage of mosquitoes resistant to DDT rose rapidly. (c) Suggest an explanation for the global spread of DDT resistance.

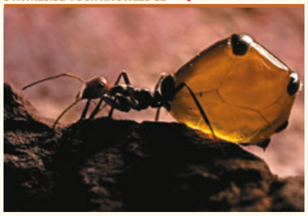
Month	0	8	12
Mosquitoes Resistant* to DDT	4%	45%	77%

*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. **SYNTHESISE 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, the fundamental theme of biology, is emphasised 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 transplanted 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).

Evolution Connection Questions are included in every Chapter Review.

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 catalysed by the protein product of the firefly gene.

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

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

Build Visual Skills

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

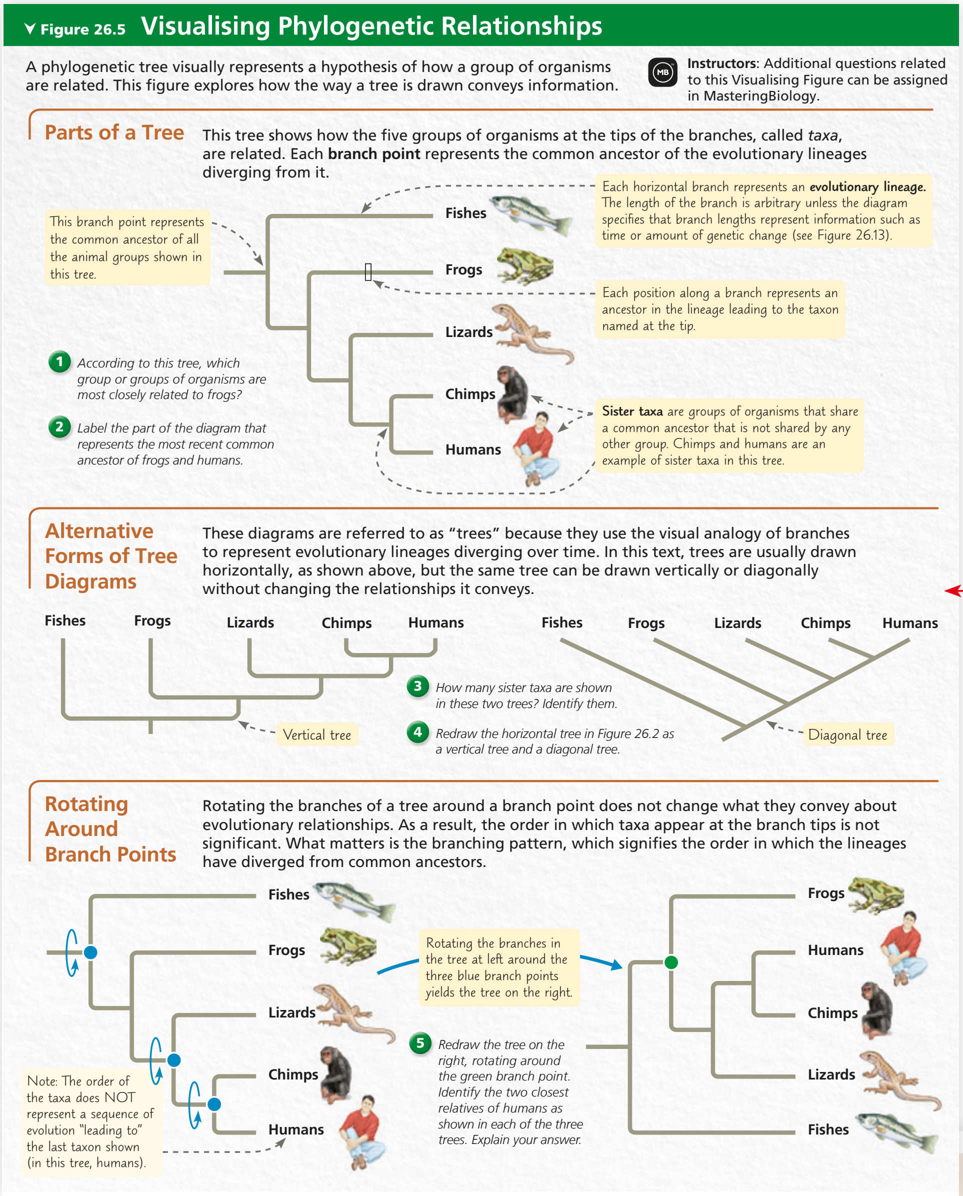


Figure 26.5 Visualising Phylogenetic Relationships

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 Visualising 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.

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.

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.*

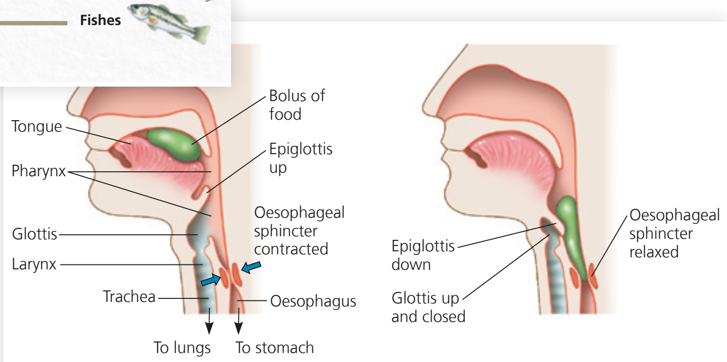
Rotating Around Branch Points

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.

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.*

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

Visualising Figures include:

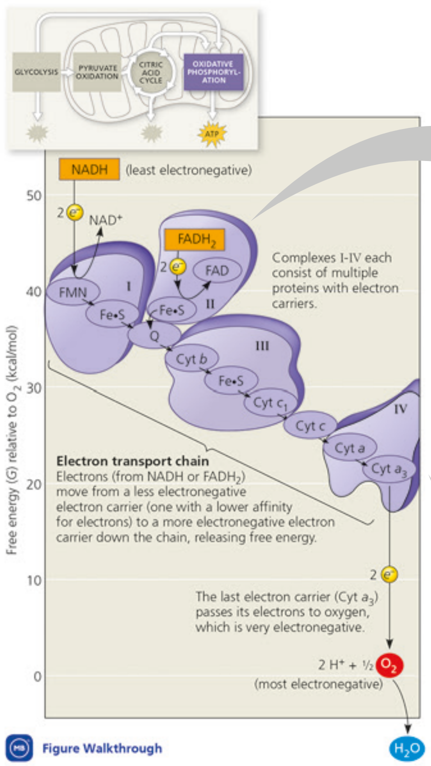


(a) Trachea open **(b) Oesophagus open**

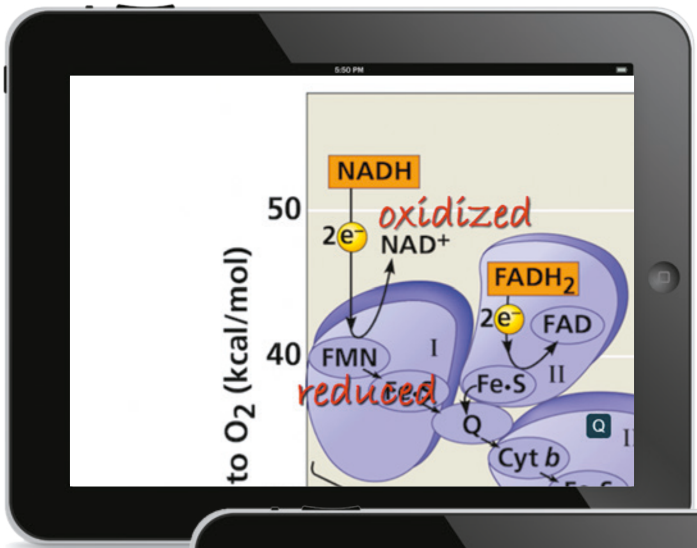
VISUAL SKILLS ➤ *If you laugh while drinking water, the liquid may be ejected from your nostrils. Use this diagram to explain why this happens, taking into account that laughing involves exhaling.*

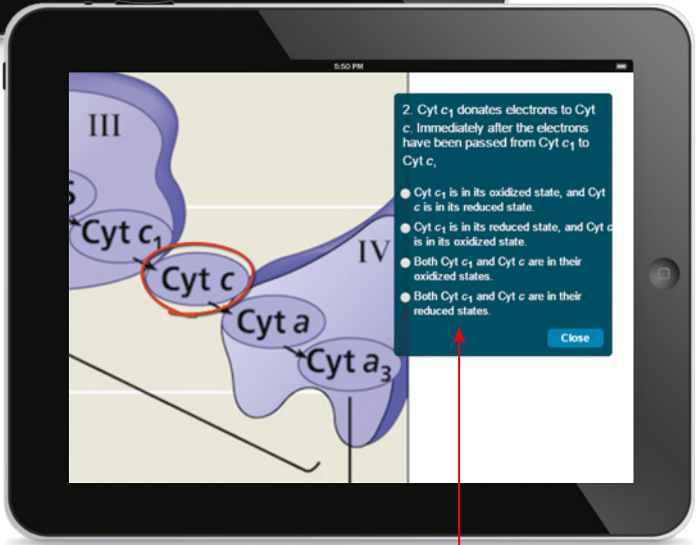
NEW! Visual Skills Questions give students practice interpreting illustrations and photos in the text.

NEW! Figure Walkthroughs guide students through key figures with narrated explanations, figure markups, and questions that reinforce important points.



A note in the print book lets students and instructors know when a Figure Walkthrough is available in the Study Area.





Questions embedded in each Figure Walkthrough encourage students to be active participants in their learning. The Figure Walkthroughs can also be assigned in MasteringBiology with higher-level questions.

➤ Figure 2.17 **Photosynthesis: a solar-powered rearrangement of matter.** *Elodea*, a freshwater plant, produces sugar by rearranging the atoms of carbon dioxide and water in the chemical process known as photosynthesis, which is powered by sunlight. Much of the sugar is then converted to other food molecules. Oxygen gas (O_2) is a by-product of photosynthesis; notice the bubbles of O_2 gas escaping from the leaves submerged in water.

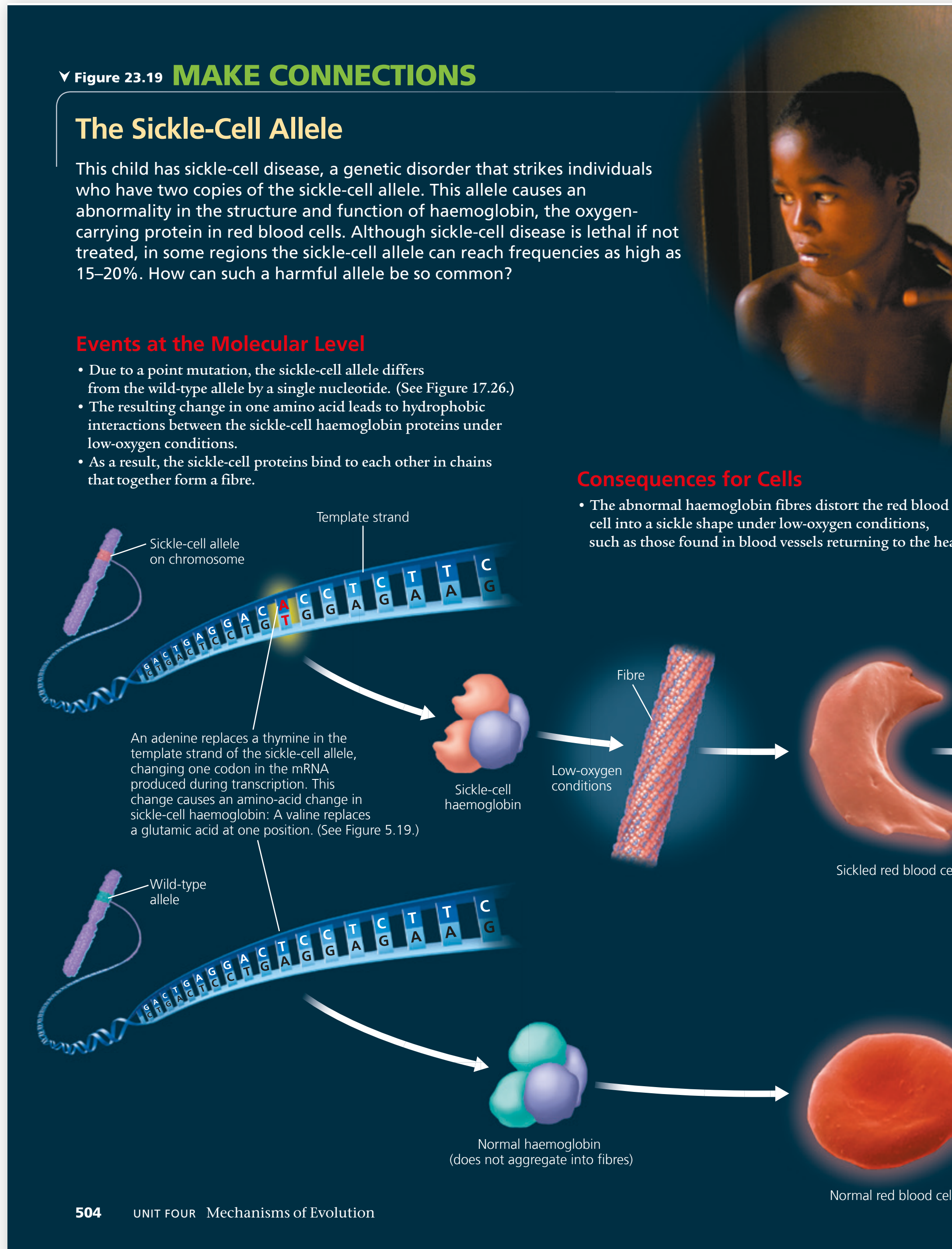
DRAW IT ➤ *Add labels and arrows on the photo showing the reactants and products of photosynthesis as it takes place in a leaf.*

EXPANDED! Draw It exercises give students practice creating visuals. Students are asked to put pencil to paper and draw a structure, annotate a figure, or graph experimental data.

Make Connections Visually

Eleven **Make Connections Figures** pull together content from different chapters, providing a visual representation of "big picture" relationships.

Make Connections Figures include:


▼ Figure 23.19 **MAKE CONNECTIONS**

The Sickle-Cell Allele

This child has sickle-cell disease, a genetic disorder that strikes individuals who have two copies of the sickle-cell allele. This allele causes an abnormality in the structure and function of haemoglobin, the oxygen-carrying protein in red blood cells. Although sickle-cell disease is lethal if not treated, in some regions the sickle-cell allele can reach frequencies as high as 15–20%. How can such a harmful allele be so common?

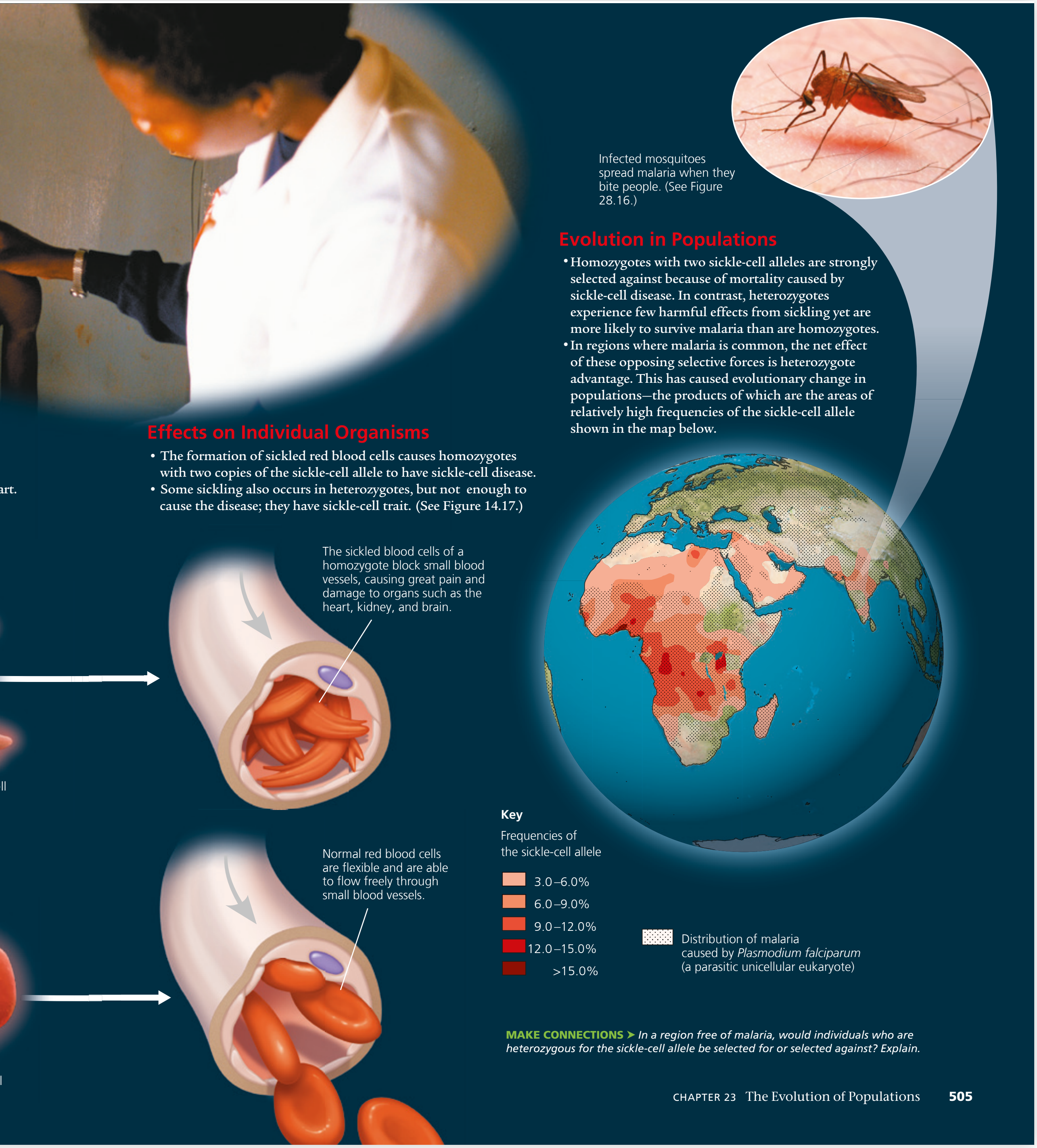
Events at the Molecular Level

- Due to a point mutation, the sickle-cell allele differs from the wild-type allele by a single nucleotide. (See Figure 17.26.)
- The resulting change in one amino acid leads to hydrophobic interactions between the sickle-cell haemoglobin proteins under low-oxygen conditions.
- As a result, the sickle-cell proteins bind to each other in chains that together form a fibre.

Consequences for Cells

- The abnormal haemoglobin fibres distort the red blood cell into a sickle shape under low-oxygen conditions, such as those found in blood vessels returning to the hea

504 UNIT FOUR Mechanisms of Evolution



Infected mosquitoes spread malaria when they bite people. (See Figure 28.16.)

Evolution in Populations

- Homozygotes with two sickle-cell alleles are strongly selected against because of mortality caused by sickle-cell disease. In contrast, heterozygotes experience few harmful effects from sickling yet are more likely to survive malaria than are homozygotes.
- In regions where malaria is common, the net effect of these opposing selective forces is heterozygote advantage. This has caused evolutionary change in populations—the products of which are the areas of relatively high frequencies of the sickle-cell allele shown in the map below.

Effects on Individual Organisms

- The formation of sickled red blood cells causes homozygotes with two copies of the sickle-cell allele to have sickle-cell disease.
- Some sickling also occurs in heterozygotes, but not enough to cause the disease; they have sickle-cell trait. (See Figure 14.17.)

MAKE CONNECTIONS ➤ *In a region free of malaria, would individuals who are heterozygous for the sickle-cell allele be selected for or selected against? Explain.*

CHAPTER 23 The Evolution of Populations 505

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

Practise Scientific Skills

Scientific Skills Exercises use real data to build key skills needed for biology, including **data analysis**, **graphing**, **experimental design** and **maths skills**.

Each Scientific Skills Exercise is based on an **experiment related to the chapter content.**

Most Scientific Skills Exercises use **data from published research,** which is cited in the exercise.

Questions build in difficulty, walking students through new skills step by step and providing opportunities for higher-level critical thinking.

SCIENTIFIC SKILLS EXERCISE

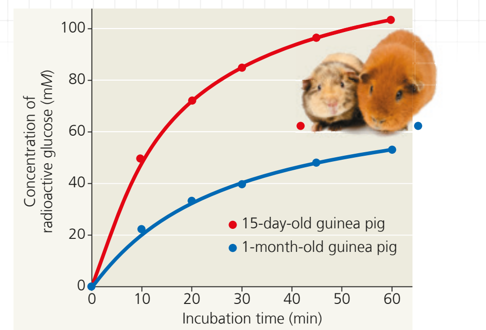
Interpreting a Scatter Plot with Two Sets of Data

Is Glucose Uptake into Cells Affected by Age? Glucose, an important energy source for animals, is transported into cells by facilitated diffusion using protein carriers. In this exercise, you will interpret a graph with two sets of data from an experiment that examined glucose uptake over time in red blood cells from guinea pigs of different ages. You will determine if the cells' rate of glucose uptake depended on the age of the guinea pigs.

How the Experiment Was Done Researchers incubated guinea pig red blood cells in a 300 m*M* (millimolar) radioactive glucose solution at pH 7.4 at 25°C. Every 10 or 15 minutes, they removed a sample of cells and measured the concentration of radioactive glucose inside those cells. The cells came from either a 15-day-old or a 1-month-old guinea pig.

Data from the Experiment When you have multiple sets of data, it can be useful to plot them on the same graph for comparison. In the graph here, each set of dots (of the same colour) forms a *scatter plot*, in which every data point represents two numerical values, one for each variable. For each data set, a curve that best fits the points has been drawn to make it easier to see the trends. (For additional information about graphs, see the Scientific Skills Review in Appendix F.)

Glucose Uptake over Time in Guinea Pig Red Blood Cells



Data from T. Kondo and E. Beutler, Developmental changes in glucose transport of guinea pig erythrocytes, *Journal of Clinical Investigation* 65:1–4 (1980).

INTERPRET THE DATA

1. First make sure you understand the parts of the graph. (a) Which variable is the independent variable—the variable controlled by the researchers? (b) Which variable is the dependent variable—the variable that depended on the treatment and was measured by the researchers? (c) What do the red dots represent? (d) The blue dots?
2. From the data points on the graph, construct a table of the data. Put "Incubation Time (min)" in the left column of the table.
3. What does the graph show? Compare and contrast glucose uptake in red blood cells from 15-day-old and 1-month-old guinea pigs.
4. Develop a hypothesis to explain the difference between glucose uptake in red blood cells from 15-day-old and 1-month-old guinea pigs. (Think about how glucose gets into cells.)
5. Design an experiment to test your hypothesis.

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

Scientific Skills Exercises are available as **interactive assignments in MasteringBiology** that are automatically graded.

SCIENTIFIC SKILLS EXERCISES are available for every chapter:

Apply Scientific Skills to Solving Problems

NEW! Problem-Solving Exercises guide students in applying scientific skills and interpreting real data in the context of solving a real-world problem.

PROBLEM-SOLVING EXERCISE

Are you a victim of fish fraud?

When buying salmon, perhaps you prefer the more expensive wild-caught Pacific salmon (*Oncorhynchus* species) over farmed Atlantic salmon (*Salmo salar*). But studies reveal that about 40% of the time, you aren't getting the fish you paid for!

In this exercise, you will investigate whether a piece of salmon has been fraudulently labelled.

Your Approach The principle guiding your investigation is that DNA sequences from within a species or from closely related species are more similar to each other than are sequences from more distantly related species.

Your Data You've been sold a piece of salmon labelled as coho salmon (*Oncorhynchus kisutch*). To see whether your fish was labelled correctly, you will compare a short DNA sequence from your sample to standard sequences from the same gene for three salmon species. The sequences are:

	Sample labelled as *O. kisutch* (coho salmon)	5′-CGGCACCGCCCTAAGTCTCT-3′
Standard sequences	Sequence for *O. kisutch* (coho salmon)	5′-AGGCACCGCCCTAAGTCTAC-3′
	Sequence for *O. keta* (chum salmon)	5′-AGGCACCGCCCTGAGCCTAC-3′
	Sequence for *Salmo salar* (Atlantic salmon)	5′-CGGCACCGCCCTAAGTCTCT-3′

Your Analysis

1. Scan along the standard sequences (*O. kisutch, O. keta*, and *S. salar*), base by base, circling any bases that do not match the sequence from your fish sample.
2. How many bases differ between (a) *O. kisutch* and your fish sample? (b) *O. keta* and the sample? (c) *S. salar* and the sample?
3. For each standard, what percentage of its bases are identical to your sample?
4. Based on these data alone, state a hypothesis for the species identity of your sample. What is your reasoning?

Problem-Solving Exercises include:

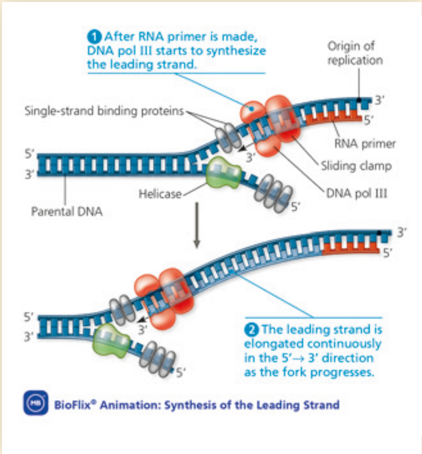
* Available only in MasteringBiology. All other Scientific Skills Exercises are in the print book, eText, and MasteringBiology.

Bring Biology to Life

NEW! More than 450 carefully chosen and edited **videos and animations** have been integrated into the print book and MasteringBiology at point of use to help students learn biology visually.

Media references in the print book direct students to digital resources in the Study Area:

- BioFlix Animations

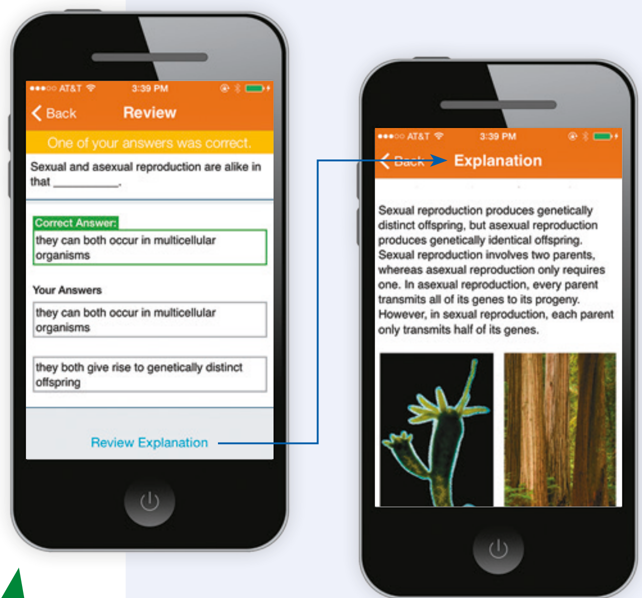


Access the complete textbook online!

The Campbell eText includes powerful interactive and customisation functions, such as instructor and student note-taking, highlighting, bookmarking, search, and links to glossary terms.

Succeed with MasteringBiology

MasteringBiology improves results by engaging students before, during, and after class.



Before Class

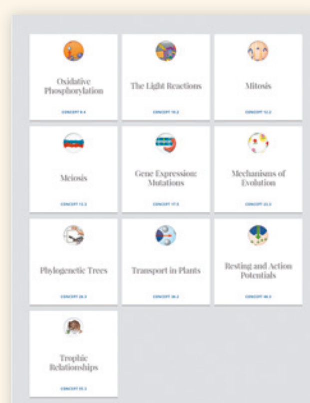
Dynamic Study Modules provide students with multiple sets of questions with extensive feedback so that they can **test, learn, and retest** until they achieve mastery of the textbook material.

NEW! Get Ready for This Chapter quizzes help students review content they need to understand from previous chapters.

Pre-Class Reading Quizzes help students pinpoint concepts that they understand and concepts that they need to review.

During Class

NEW! For ideas for in-class activities, see the **Ready-to-Go Teaching Modules**.



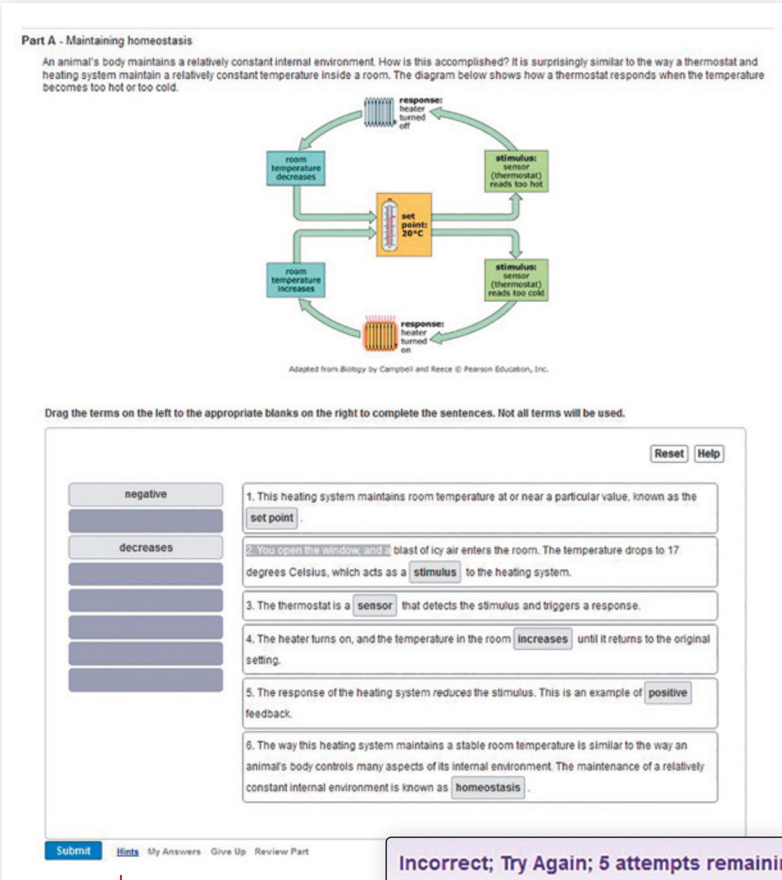
After Class

Hundreds of self-paced tutorials and coaching activities provide students with individualised coaching with specific hints and feedback on the toughest topics in the course.

Optional Adaptive Follow-up Assignments are based on each student's performance on the original MasteringBiology assignment and provide additional questions and activities tailored to each student's needs.

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

Personalised Coaching in MasteringBiology

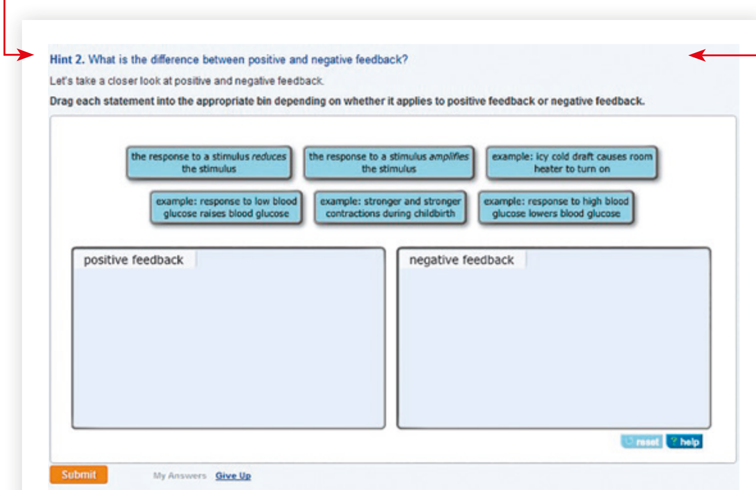


Instructors can assign self-paced **MasteringBiology tutorials** that provide students with individualised coaching with specific hints and feedback on the toughest topics in the course.

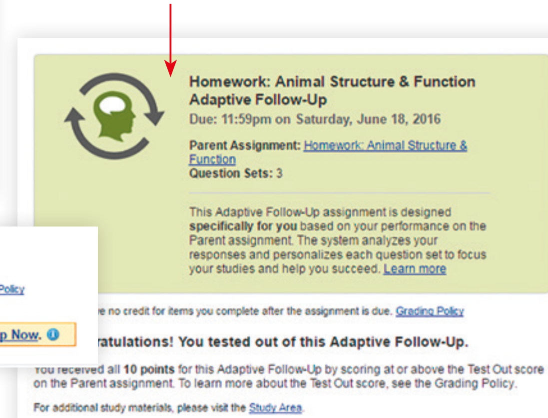
1. If a student gets stuck...
2. Specific wrong-answer **feedback** appears in the purple feedback box.

Incorrect; Try Again; 5 attempts remaining

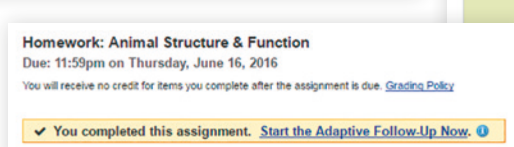
You filled in 1 of 6 blanks incorrectly. For sentence 5, you may want to review positive and negative feedback in Hint 2.



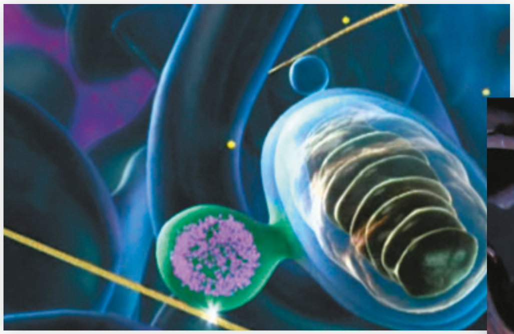
3. **Hints** coach students to the correct response.
4. Optional **Adaptive Follow-Up Assignments** are based on the original homework assignment and provide additional coaching and practice as needed.



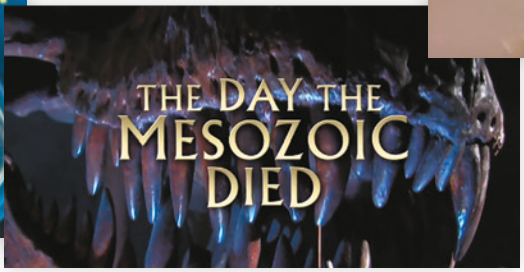
Question sets in the Adaptive Follow-Up Assignments **continuously adapt** to each student's needs, making efficient use of study time.



MasteringBiology offers thousands of tutorials, activities, and questions that can be assigned as homework. A few examples are shown below.



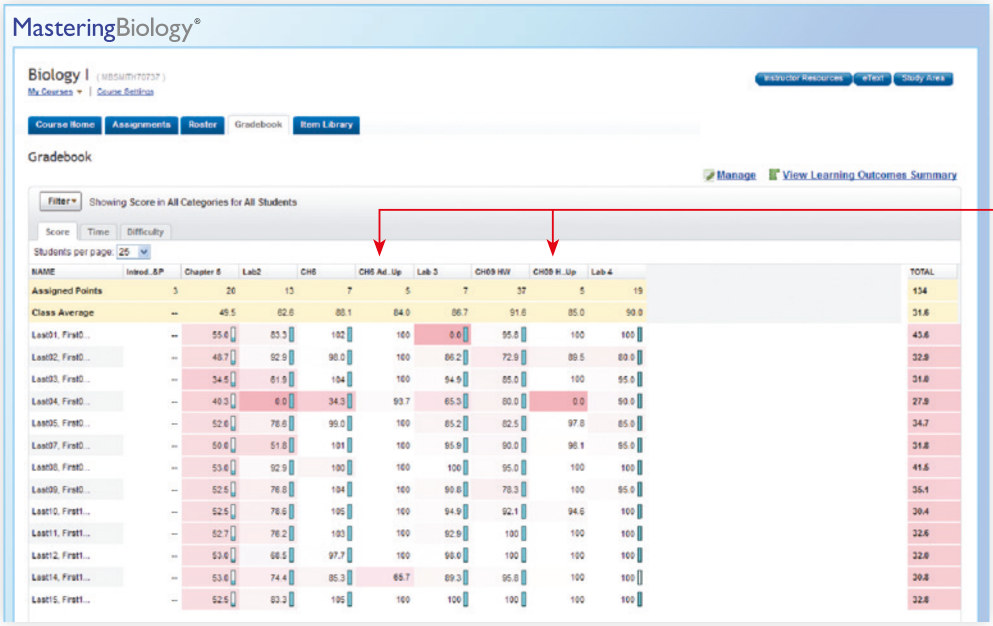
BioFlix Tutorials use 3D, movie-quality animations and coaching exercises to help students master tough topics outside of class. Animations are also available in the Study Area and can be shown in class.



EXPANDED! HHMI BioInteractive Short Films, documentary-quality movies from the Howard Hughes Medical Institute, engage students in topics from the discovery of the double helix to evolution, with assignable questions.

NEW! Galápagos Evolution Video Activities, filmed on the Galápagos Islands by Peter and Rosemary Grant, bring to life the dynamic evolutionary processes that impact Darwin's finches on Daphne Major Island. Videos explore important concepts and data from the Grants' field research, with assignable activities.

The **MasteringBiology Gradebook** provides instructors with quick results and easy-to-interpret insights into student performance. Every assignment is automatically graded. Shades of red highlight vulnerable students and challenging assignments.



Student scores on the optional **Adaptive Follow-Up Assignments** are recorded in the gradebook and offer additional diagnostic information for instructors to monitor learning outcomes and more.

Instructor Resources

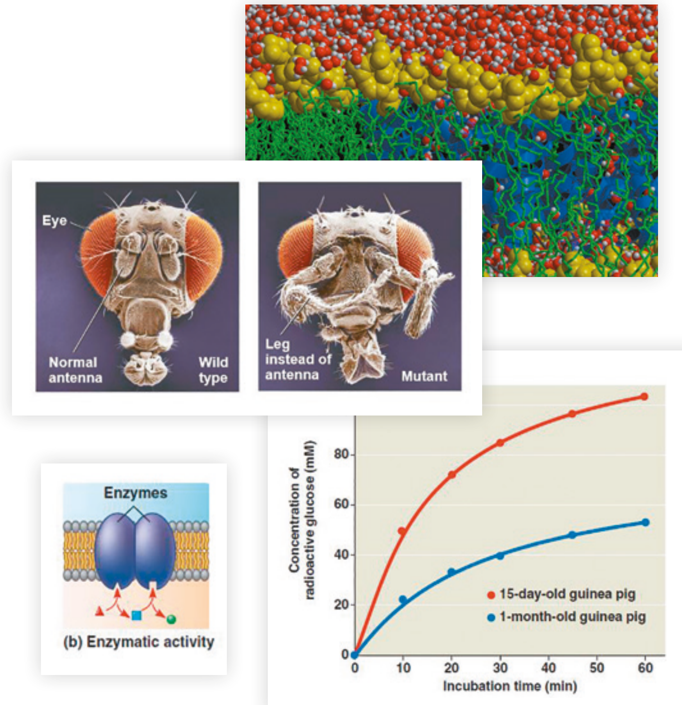
Instructor's Resource USB Set for Campbell Biology, Eleventh Edition

The Instructor's Resource USB consists of a set of assets for each chapter. Specific features include:

- Editable figures (art and photos) and tables from the text in PowerPoint®
- Test Bank questions.

The Instructor Resources area of MasteringBiology includes:

- **NEW!** Ready-to-Go Teaching Modules help instructors efficiently make use of the available teaching tools for the toughest topics. Before-class assignments, in-class activities, and after-class assignments are provided for ease of use. Instructors can incorporate active learning into their course with the suggested activity ideas and clicker questions or Learning Catalytics questions.
- Editable figures (art and photos) and tables from the text in PowerPoint
- Testbank questions.



▲ All of the art, graphs, and photos from the text are provided with customisable labels. More than 1,600 photos from the text and other sources are included.

Featured Figures

Visualising Figures

Make Connections Figures

Exploring Figures

Inquiry Figures

Research Method Figures

*The Inquiry Figure, original research paper, and a worksheet to guide you through the paper are provided in *Inquiry in Action: Interpreting Scientific Papers*, Fourth Edition.
†A related Experimental Inquiry Tutorial can be assigned in MasteringBiology.®

Interviews

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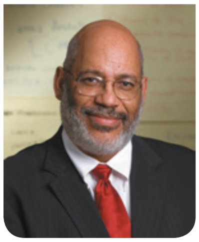

Lovell Jones

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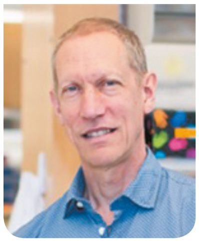

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Acknowledgments

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While only a few names appear on the cover of any book, there is literally an army of people whose creative energy shaped the book. To the production team here in Australia, without your efforts the book would never have reached fruition. It is always challenging to single out a few for truly exemplary contributions. Nicole Le Grand and Caroline Hunter have my heartfelt appreciation, as do Mandy Sheppard, Emma Gaulton and Bernadette Chang. Thanks to Nick Mortimer and Adrian Dyer whose interviews add to the biological distinctiveness of our understandings of the Southern Hemisphere.

Noel Meyers

US Edition

The authors wish to express their gratitude to the global community of instructors, researchers, students, and publishing professionals who have contributed to the Eleventh Edition of *CAMPBELL BIOLOGY*.

As authors of this text, we are mindful of the daunting challenge of keeping up to date in all areas of our rapidly expanding subject. We are grateful to the many scientists who helped shape this text by discussing their research fields with us, answering specific questions in their areas of expertise, and sharing their ideas about biolog y education. We are especially grateful to the following, listed alphabetically: Graham Alexander, John Archibald, Kristian Axelsen, Barbara Bowman, Joanne Chory, Roger Craig, Michael Hothorn, Patrick Keeling, Barrett Klein, Rachel Kramer Green, James Nieh, Kevin Peterson, T.K. Reddy, Andrew Roger, Alastair Simpson, Marty Taylor, and Elisabeth Wade. In addition, the biologists listed on pages xxviii–xxxi provided detailed reviews, helping us ensure the text's scientific accuracy and improve its pedagogical effectiveness. We thank Michael Pollock, author of the Study Guide, for his many contributions to the accuracy, clarity, and consistency of the text; and we thank Carolyn Wetzel, Ruth Buskirk, Joan Sharp, Jennifer Yeh, and Charlene D'Avanzo for their contributions to the Scientific Skills Exercises and Problem-Solving Exercises.

Thanks also to the other professors and students, from all over the world, who contacted the authors directly with useful suggestions. We alone bear the responsibility for any errors that remain, but the dedication of our consultants, reviewers, and other correspondents makes us confident in the accuracy and effectiveness of this text.

Interviews with prominent scientists have been a hallmark of *CAMPBELL BIOLOGY* since its inception, and conducting these interviews was again one of the great pleasures of revising the book. To open the eight units of this edition, we are proud to include interviews with Lovell Jones, Elba Serrano, Shirley Tilghman, Jack Szostak, Philip Benfey, and Tracy Langkilde.

We are especially grateful to Rebecca Orr for her hard work on the digital resources for the eText, Study Area, and Ready-to-Go Teaching Modules. And thanks to the rest of the Ready-to-Go Teaching Modules team: Molly Jacobs, Karen Resendes, Eileen Gregory, Angela Hodgson, Maureen Leupold, Jennifer Metzler, Allison Silveus, Jered Studinski, Sara Tallarovic, Judy Schoonmaker, Michael Pollock, and Chad Brassil. We would also like to extend our sincere appreciation to Carolyn Wetzel, Jennifer Yeh, Matt Lee, and Sherry Seston for their hard work on the Figure Walkthroughs. And our gratitude goes to Katie Cook for keeping these projects so well organised. Thanks also to Kaddee Lawrence for writing the questions that accompany the Visualising Figures in MasteringBiology and to Mikaela Schmitt-Harsh for converting the Problem-Solving Exercises to MasteringBiology tutorials.

The value of *CAMPBELL BIOLOGY* as a learning tool is greatly enhanced by the supplementary materials that have been created for instructors and students. We recognise that the dedicated authors of these materials are essentially writing mini (and not so mini) books. We appreciate the hard work and creativity of all the authors listed, with their creations, on page xxii. We are also grateful to Kathleen Fitzpatrick and Nicole Tunbridge (PowerPoint® Lecture Presentations); Roberta Batorsky, Douglas Darnowski, James Langeland, and David Knochel (Clicker Questions); Sonish Azam, Kevin Friesen, Murty Kambhampati, Janet Lanza, Ford Lux, Chris Romero, Ruth Sporers, and David Knochel (Test Bank); Natalie Bronstein, Linda Logdberg, Matt McArdle, Ria Murphy, Chris Romero, and Andy Stull (Dynamic Study Modules); and Eileen Gregory, Rebecca Orr, and Elena Pravosudova (Adaptive Follow-up Assignments).

MasteringBiology™ and the other electronic accompaniments for this text are invaluable teaching and learning aids. We thank the hardworking, industrious instructors who worked on the revised and new media: Roberta Batorsky, Beverly Brown, Erica Cline, Willy Cushwa, Tom Kennedy, Tom Owens, Michael Pollock, Frieda Reichsman, Rick Spinney, Dennis Venema, Carolyn Wetzel, Heather Wilson-Ashworth, and Jennifer Yeh. We are also grateful to the many other people—biology instructors, editors, and production experts—who are listed in the credits for these and other elements of the electronic media that accompany the text.

CAMPBELL BIOLOGY results from an unusually strong synergy between a team of scientists and a team of publishing professionals.

Our editorial team at Pearson Education again demonstrated unmatched talents, commitment, and pedagogical insights. Our Courseware Portfolio Management Specialist, Josh Frost, brought publishing savvy, intelligence, and a much-appreciated level head to leading the whole team. The clarity and effectiveness of every page owe much to our extraordinary Supervising Editors Beth Winickoff and Pat Burner, who worked with a top-notch team of Courseware Senior Analysts in John Burner, Mary Ann Murray, Mary Hill, Laura Southworth, and Hilair Chism. Our unsurpassed Courseware Director of Content Development Ginnie Simione Jutson and Courseware Portfolio Management Director Beth Wilbur were indispensable in moving the project in the right direction. We also want to thank Robin Heyden for organising the annual Biology Leadership Conferences and keeping us in touch with the world of AP Biology.

You would not have this beautiful text if not for the work of the production team: Director of Product Management Services Erin Gregg; Managing Producer Michael Early; Content Producer Lori Newman; Photo Researcher Maureen Spuhler; Copy Editor Joanna Dinsmore; Proofreader Pete Shanks; Rights & Permissions Manager Ben Ferrini; Managing Editor Angel Chavez and the rest of the staff at Integra Software Services, Inc.; Art Production Manager Rebecca Marshall, Artist Kitty Auble, and the rest of the staff at Lachina; Design Manager Marilyn Perry; Text and Cover Designer Elise Lansdon; and Manufacturing Buyer Stacey Weinberger. We also thank those who worked on the text's supplements: Josey Gist, Margaret Young, Kris Langan, Pete Shanks, Crystal Clifton and Jennifer Hastings at Progressive Publishing Alternatives, and Margaret McConnell at Integra. And for creating the wonderful package of electronic media that accompanies the text, we are grateful to Tania Mlawer, Sarah Jensen, Charles Hall, Katie Foley, Laura Tommasi, Lee Ann Doctor, Tod Regan, Libby Reiser, Jackie Jakob, Sarah Young-Dualan, Cady Owens, Caroline Ayres, Katie Cook, and Ziki Dekel as well as VP of Production and Digital Studio Lauren Fogel and Director of Digital Content Development Portfolio Management Stacy Treco.

For their important roles in marketing the text and media, we thank Christy Lesko, Lauren Harp, Kelly Galli, and Jane Campbell. For her market development support, we thank Jessica Moro. We are grateful to Adam Jaworski, VP Portfolio Management, Science, and Paul Corey, Managing Director, Higher Education Courseware, for their enthusiasm, encouragement, and support.

The Pearson sales team, which represents *CAMPBELL BIOLOGY* on campus, is an essential link to the users of the text. They tell us what you like and don't like about the text, communicate the features of the text, and provide prompt service. We thank them for their hard work and professionalism. For representing our text to our international audience, we thank our sales and marketing partners throughout the world. They are all strong allies in biology education.

Finally, we wish to thank our families and friends for their encouragement and patience throughout this long project. Our special thanks to Ross, Lily, and Alex (L.A.U.); Debra and Hannah (M.L.C.); Aaron, Sophie, Noah, and Gabriele (S.A.W.); Natalie (P.V.M.); and Paul, Dan, Maria, Armelle, and Sean (J.B.R.). And, as always, thanks to Rochelle, Allison, Jason, McKay, and Gus.

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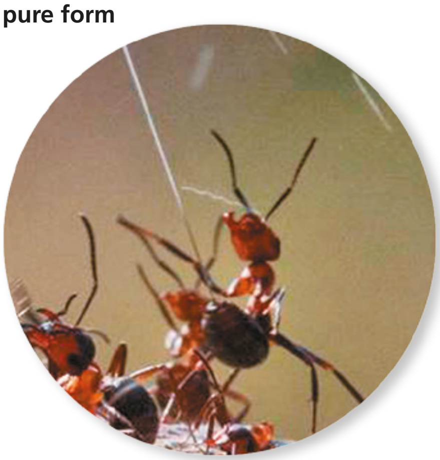

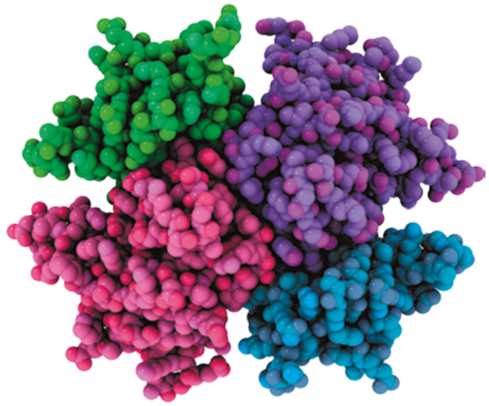

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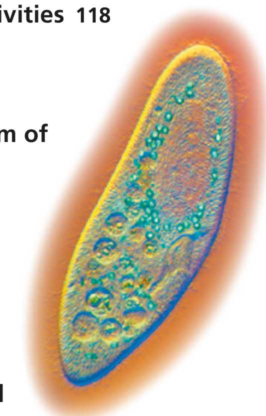

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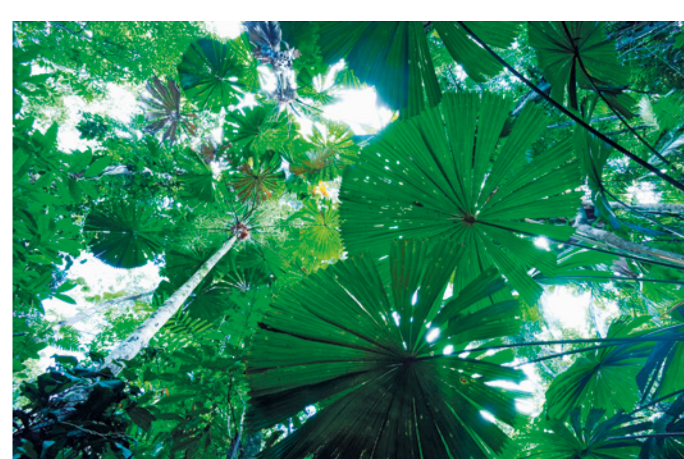

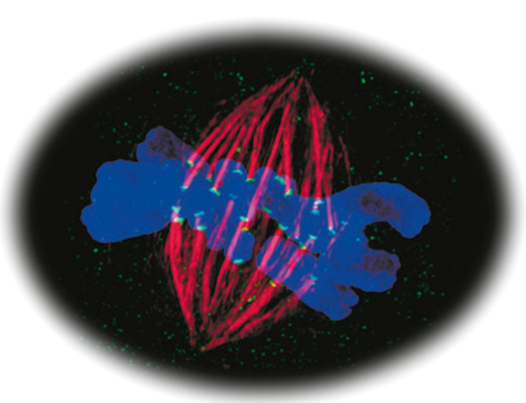

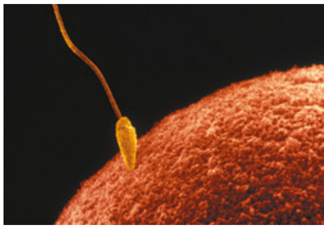

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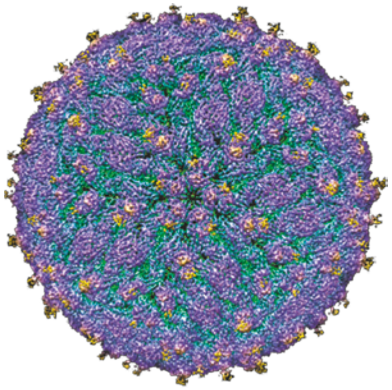

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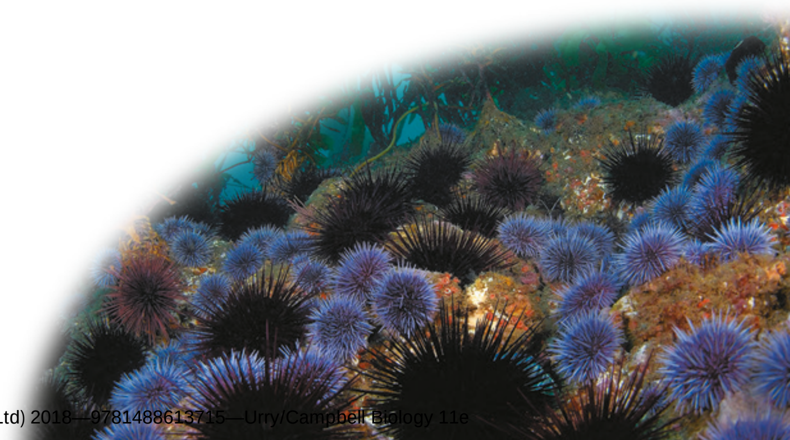

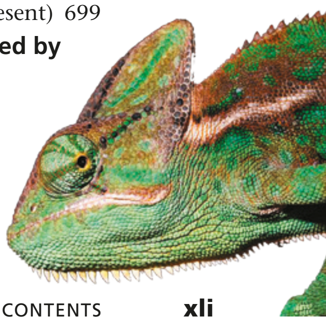

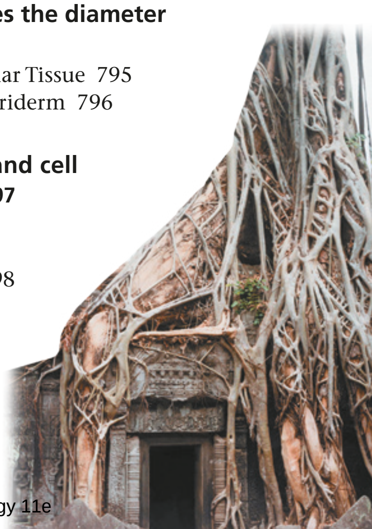

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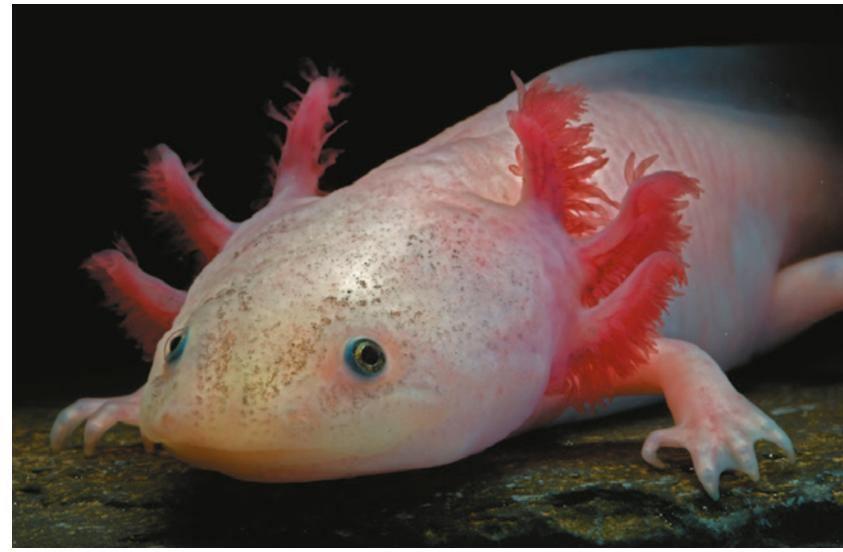

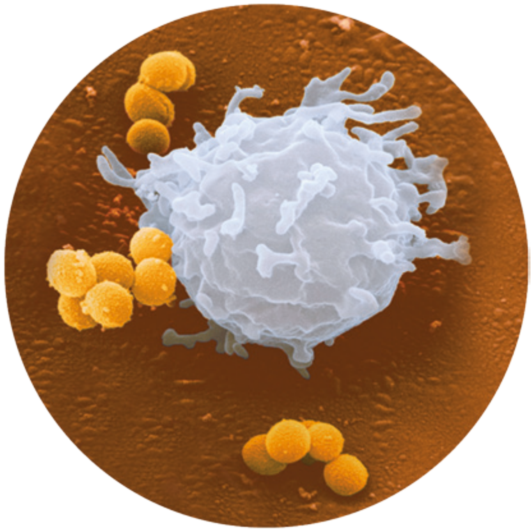

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1 Evolution, the Themes of Biology, and Scientific Inquiry

Figure 1.1 **A western pygmy possum (*Cercartetus concinnus*) seeking nectar in a banksia flower.**

KEY CONCEPTS

1.1 The study of life reveals unifying themes

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

1.3 In studying nature, scientists make observations and form and test hypotheses

1.4 Science benefits from a cooperative approach and diverse viewpoints

The characteristic red-tinged fur of the barely 9 cm long western pygmy possum distinguishes the animal from its grey-coated eastern cousins.

Inquiring About Life

In brief periods of fine weather, you might be lucky enough to see a western pygmy possum (*Cercartetus concinnus*) emerge from a tree or rock hollow in Australia's south-west. These solitary, nocturnal animals forage for pollen and nectar in plants like the scarlett banksia (*Banksia coccinea*) (**Figure 1.1**). Barely 9 cm long, the western pygmy possum relies on an energy-rich diet to fuel a metabolism so rapid that failing to eat on successive nights may see the animal starve to death. Thus, during periods of cold and/or rain, which could prove fatal to the possum, the animal enters an incredibly deep sleep, called torpor. A very slow heartbeat, limited oxygen consumption, and a body temperature cooled to only a degree or two above the air temperature in its hollow allow the animal to conserve energy for up to a week. How has the pygmy possum's ability to enter torpor matched, or *adapted*, to the local conditions?

An organism's adaptations to its environment are the result of *evolution*, the process of change over time that has resulted in the astounding array of organisms found on Earth. Evolution is the fundamental principle of biology and the core theme of this book.

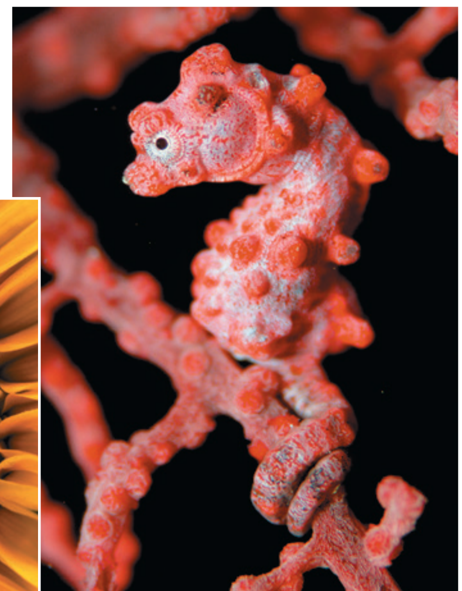
Although biologists know a great deal about life on Earth, many mysteries remain. Posing questions about the living world and seeking answers through scientific inquiry are the central activities of **biology**, the scientific study of life. Biologists' questions can be ambitious. They may ask how a single tiny cell becomes a tree or a dog, how the human mind works, or how the different forms of life in a forest interact. When questions occur to you as you observe the natural world, you are thinking like a biologist. More than anything else, biology is a quest, an ongoing inquiry about the nature of life.

At the most fundamental level, we may ask: What is life? Even a child realises that a dog or a plant is alive, while a rock or a car is not. Yet the phenomenon we call life defies a simple, one-sentence definition. We recognise life by what living things do. **Figure 1.2** highlights some of the properties and processes we associate with life.

While limited to a handful of images, Figure 1.2 reminds us that the living world is wondrously varied. How do biologists make sense of this diversity and complexity? This opening chapter sets up a framework for answering this question. The first part of the chapter provides a panoramic view of the biological "landscape," organised around some unifying themes. We then focus on biology's core theme, evolution, which accounts for life's unity and diversity. Next, we look at scientific inquiry—how scientists ask and attempt to answer questions about the natural world. Finally, we address the culture of science and its effects on society.

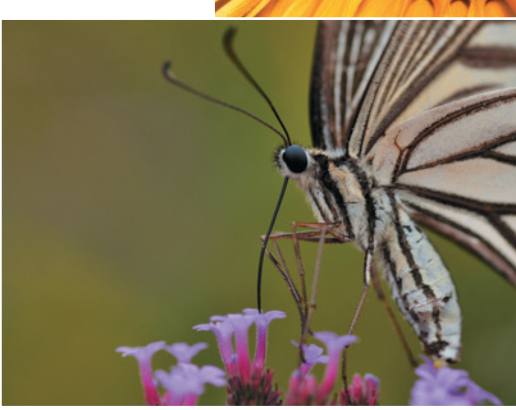
▼ **Figure 1.2 Some properties of life.**

▼ **Order.** This close-up of a sunflower illustrates the highly ordered structure that characterises life.



▲ **Evolutionary adaptation.** The overall appearance of this pygmy sea horse camouflages the animal in its environment. Such adaptations evolve over countless generations by the reproductive success of those individuals with heritable traits that are best suited to their environments.

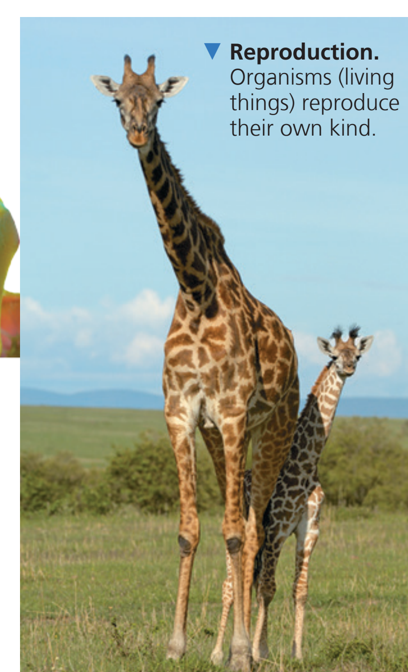
▲ **Regulation.** The regulation of blood flow through the blood vessels of this bilby's ears helps maintain a constant body temperature by adjusting heat exchange with the surrounding air.



▲ **Energy processing.** This butterfly obtains fuel in the form of nectar from flowers. The butterfly will use chemical energy stored in its food to power flight and other work.

▲ **Growth and development.** Inherited information carried by genes controls the pattern of growth and development of organisms, such as this oak seedling.

▲ **Response to the environment.** The Venus flytrap on the left closed its trap rapidly in response to the environmental stimulus of a grasshopper landing on the open trap.



▼ **Reproduction.** Organisms (living things) reproduce their own kind.

CONCEPT 1.1

The study of life reveals unifying themes

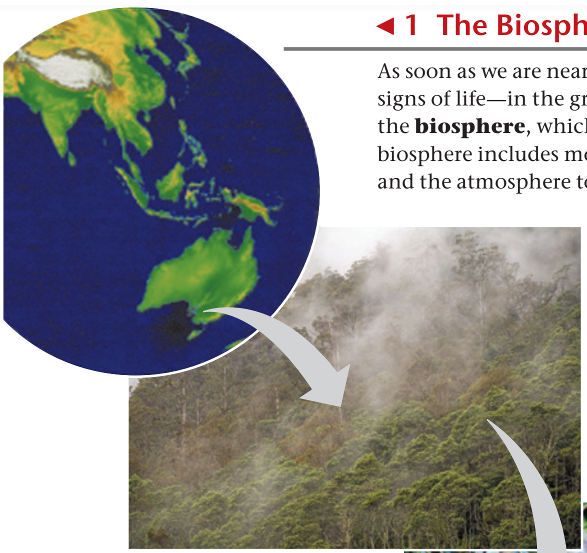
Biology is a subject of enormous scope, and exciting new biological discoveries are being made every day. How can you organise into a comprehensible framework all the information you'll encounter as you study the broad range of topics included in biology? Focusing on a few big ideas will help.

Here are five unifying themes—ways of thinking about life that will still hold true decades from now.

- Organisation
- Information
- Energy and Matter
- Interactions
- Evolution

In this section and the next, we'll briefly define and explore each theme.

▼ Figure 1.3 Exploring Levels of Biological Organisation



◀ 1 The Biosphere

As soon as we are near enough to Earth to make out its continents and oceans, we begin to see signs of life—in the green mosaic of the planet's forests, for example. This is our first view of the **biosphere**, which consists of all the environments on Earth that are inhabited by life. The biosphere includes most regions of land; most bodies of water, such as oceans, lakes, and rivers; and the atmosphere to an altitude of several kilometres.

◀ 2 Ecosystems

As we approach Earth's surface for an imaginary landing in north-eastern Victoria, we can begin to make out a forest with an abundance of eucalypts. Such a eucalypt forest is an example of an **ecosystem**. Grasslands, deserts, and the ocean's coral reefs are other types of ecosystems. An ecosystem consists of all the living things in a particular area, along with all the nonliving components of the environment with which life interacts, such as soil, water, atmospheric gases, and light. All of Earth's ecosystems combined make up the biosphere.

▶ 3 Communities

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

▶ 4 Populations

A **population** consists of all the individuals of a species living within the bounds of a specified area. For example, our north-eastern Victorian forest includes a population of eucalypts and a population of koalas. We can now refine our definition of a community as the set of populations that inhabit a particular area.

▲ 5 Organisms

Individual living things are called **organisms**. Each of the trees and other plants in the forest is an organism, and so is each forest animal such as a frog, lizard, koala, and insects. The soil teems with microorganisms such as bacteria.

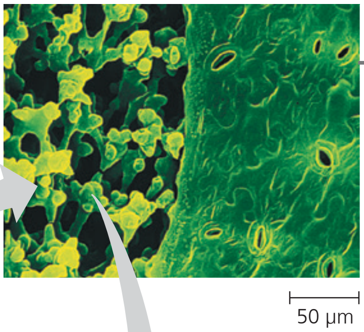
Theme: New Properties Emerge at Successive Levels of Biological Organisation

ORGANISATION The study of life on Earth extends from the microscopic scale of the molecules and cells that make up organisms to the global scale of the entire living planet. As biologists, we can divide this enormous range into different levels of biological organisation. In **Figure 1.3**, we zoom in from space to take a closer and closer look at life in a eucalypt forest in eastern Victoria. This journey, depicted as a series of numbered steps, highlights the hierarchy of biological organisation.

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

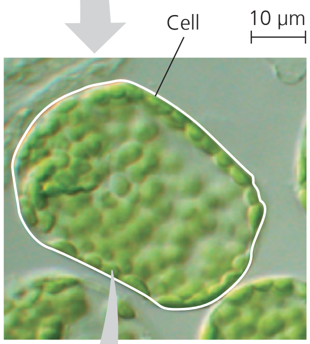
▼ 6 Organs and Organ Systems

The structural hierarchy of life continues to unfold as we explore the architecture of the more complex organisms. A eucalypt leaf is an example of an **organ**, a body part consisting of two or more tissues (which we'll see upon our next scale change). Stems and roots are the other major organs of plants. Examples of human organs are the brain, heart, and kidneys. The organs of humans and other complex animals are organised into *organ systems*, each a team of organs that cooperate in a specific function. For example, the human digestive system includes such organs as the tongue, stomach, and intestines.



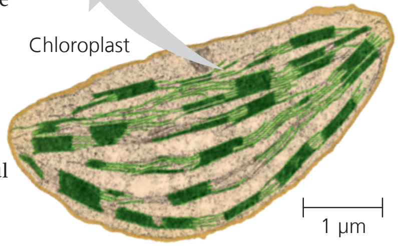
◀ 7 Tissues

Our next scale change—to see a leaf's **tissues**—requires a microscope. The leaf on the left has been cut on an angle. The honeycombed tissue in the interior of the leaf (left side of photo) is the main location of photosynthesis, the process that converts light energy to the chemical energy of sugar and other food. We are viewing the sliced leaf from a perspective that also enables us to see the jigsaw puzzle-like tissue called epidermis, the "skin" on the surface of the leaf (right side of photo). The pores through the epidermis allow the gas carbon dioxide (CO_2), a raw material for sugar production, to reach the photosynthetic tissue in the interior of the leaf. At this scale, we can also see that each tissue has a cellular structure. In fact, each kind of tissue is a group of similar cells.



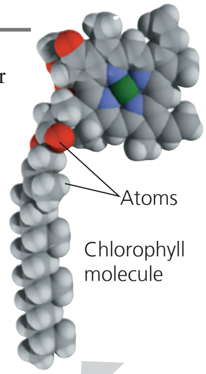
▲ 8 Cells

The **cell** is life's fundamental unit of structure and function. Most organisms, such as amoebas and most bacteria, are single cells. Some organisms, including plants and animals, are multicellular. Instead of a single cell performing all the functions of life, a multicellular organism has a division of labour among specialised cells. A human body consists of trillions of microscopic cells of many different kinds, including muscle cells and nerve cells, which are organised into the various specialised tissues. For example, muscle tissue consists of bundles of muscle cells. And note again the cells of the tissue within a leaf's interior. Each of the cells you see is about 25 µm (micrometres) across. It would take 65 of these cells to reach across an "O" on this page. As small as these cells are, you can see that each contains numerous green structures called chloroplasts, which are responsible for photosynthesis.



▶ 9 Organelles

Chloroplasts are examples of **organelles**, the various functional components that make up cells. In this figure, a very powerful tool called an electron microscope brings a single chloroplast into sharp focus.



▶ 10 Molecules

Our last scale change vaults us into a chloroplast for a view of life at the molecular level. A **molecule** is a chemical structure consisting of two or more small chemical units called *atoms*, which are represented as balls in this computer graphic of a chlorophyll molecule. Chlorophyll is the pigment molecule that makes a eucalypt leaf green. One of the most important molecules on Earth, chlorophyll absorbs sunlight during the first step of photosynthesis. Within each chloroplast, millions of chlorophylls and other molecules are organised into the equipment that converts light energy to the chemical energy of food.

Emergent Properties

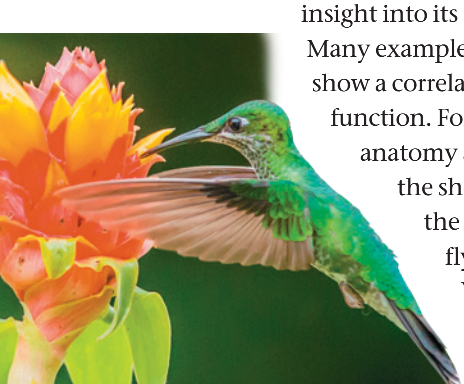
Let's reexamine Figure 1.3, beginning this time at the molecular level and then zooming out. This approach allows us to see novel properties emerge at each level that are absent from the preceding one. These **emergent properties** are due to the arrangement and interactions of parts as complexity increases.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

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

To fully explore emergent properties, biologists today complement reductionism with **systems biology**, the exploration of a biological system by analysing the interactions among its parts. In this context, a single leaf cell can be considered a system, as can a frog, an ant colony, or a desert ecosystem. By examining and modeling the dynamic behaviour of an integrated network of components, systems biology enables us to pose new kinds of questions. For example, how do networks of molecular interactions in our bodies generate our 24-hour cycle of wakefulness and sleep? At a larger scale, how does a gradual increase in atmospheric carbon dioxide alter ecosystems and the entire biosphere? Systems biology can be used to study life at all levels.

Structure and Function

At each level of the biological hierarchy, we find a correlation of structure and function. Consider a leaf in Figure 1.3: Its thin, flat shape maximises the capture of sunlight by chloroplasts. Because such correlations of structure and function are common in all forms of life, analysing a biological structure gives us clues about what it does and how it works. Conversely, knowing the function of something provides insight into its structure and organisation. Many examples from the animal kingdom show a correlation between structure and function. For example, the hummingbird's anatomy allows the wings to rotate at the shoulder, so hummingbirds have the ability, unique among birds, to fly backwards or hover in place. While hovering, the birds can extend their long, slender beaks into flowers and feed on nectar. The elegant match of form and function in the structures of life is explained by natural selection, which we'll explore shortly.



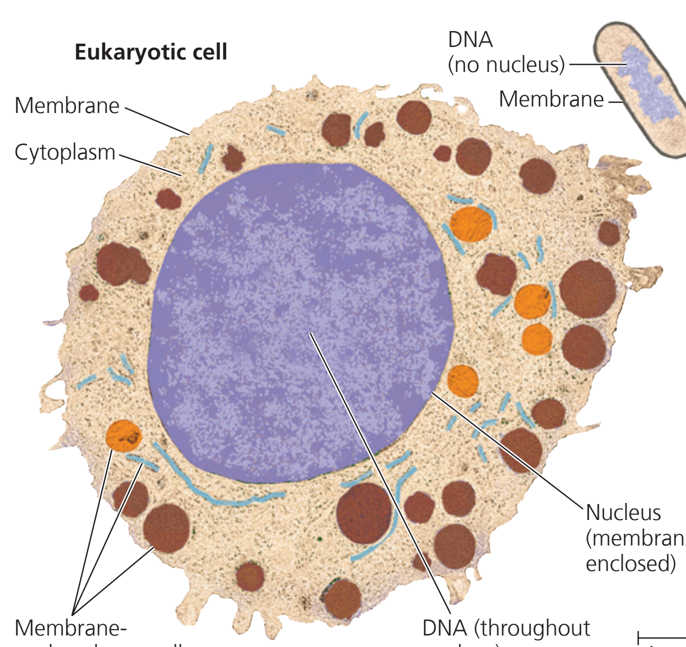
The Cell: An Organism's Basic Unit of Structure and Function

In life's structural hierarchy, the cell is the smallest unit of organisation that can perform all activities required for life. The so-called Cell Theory was first developed in the 1800s, based on the observations of many scientists. The theory states that all living organisms are made of cells, which are the basic unit of life. In fact, the actions of organisms are all based on the functioning of cells. For instance, the movement of your eyes as you read this sentence results from the activities of muscle and nerve cells. Even a process that occurs on a global scale, such as the recycling of carbon atoms, is the product of cellular functions, including the photosynthetic activity of chloroplasts in leaf cells.

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

A **eukaryotic cell** contains membrane-enclosed organelles **(Figure 1.4)**. Some organelles, such as the DNA-containing nucleus, are found in the cells of all eukaryotes; other organelles

▼ Figure 1.4 Contrasting eukaryotic and prokaryotic cells in size and complexity. The cells are shown to scale here; to see a larger magnification of a prokaryotic cell, see Figure 6.5.



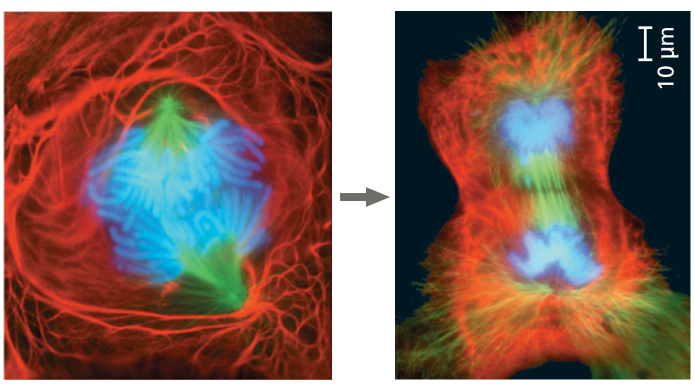
VISUAL SKILLS ➤ *Measure the scale bar and use its length to estimate the length of the prokaryotic cell and the longest dimension of the eukaryotic cell.*

are specific to particular cell types. For example, the chloroplast in Figure 1.3 is an organelle found only in eukaryotic cells that carry out photosynthesis. In contrast to eukaryotic cells, a **prokaryotic cell** lacks a nucleus or other membrane-enclosed organelles. Furthermore, prokaryotic cells are generally smaller than eukaryotic cells, as shown in Figure 1.4.

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

INFORMATION Within cells, structures called chromosomes contain genetic material in the form of **DNA (deoxyribonucleic acid)**. In cells that are preparing to divide, the chromosomes may be made visible using a dye that appears blue when bound to the DNA **(Figure 1.5)**.

Figure 1.5 A lung cell from a newt divides into two smaller cells that will grow and divide again.



DNA, the Genetic Material

Before a cell divides, the DNA is first replicated, or copied, and each of the two cellular offspring inherits a complete set of chromosomes, identical to that of the parent cell. Each chromosome contains one very long DNA molecule with hundreds or thousands of **genes**, each a section of the DNA of the chromosome. Transmitted from parents to offspring, genes are the units of inheritance. They encode the information necessary to build all of the molecules synthesised within a cell, which in turn establish that cell's identity and function. You began as a single cell stocked with DNA inherited from your parents. The replication of that DNA prior to each cell division transmitted copies of the DNA to what eventually became the trillions of cells of your body. As the cells grew and divided, the genetic information encoded by the DNA directed your development **(Figure 1.6)**.

The molecular structure of DNA accounts for its ability to store information. A DNA molecule is made up of two long chains, called strands, arranged in a double helix. Each chain is made up of four kinds of chemical building blocks called nucleotides, which are named adenine (A), guanine (G), cytosine (C), and thymine (T) **(Figure 1.7)**. Specific sequences of these four nucleotides encode the information

Figure 1.6 Inherited DNA directs development of an organism.

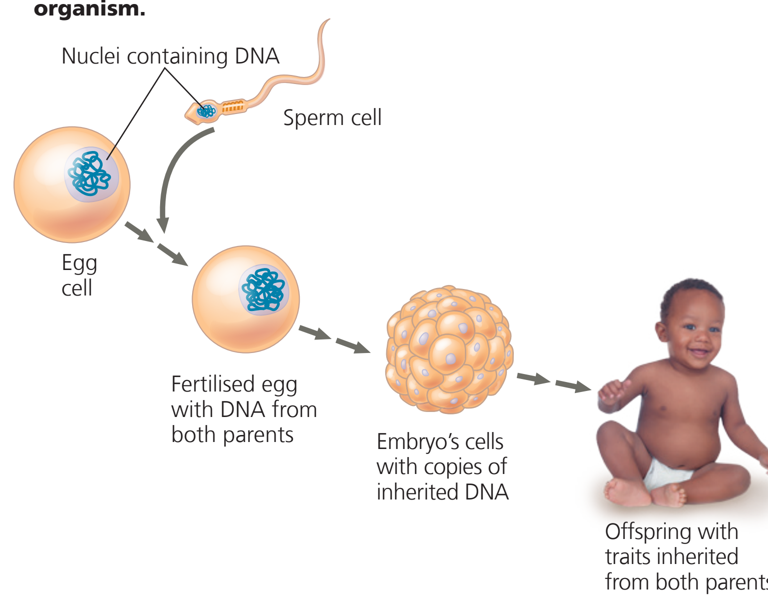
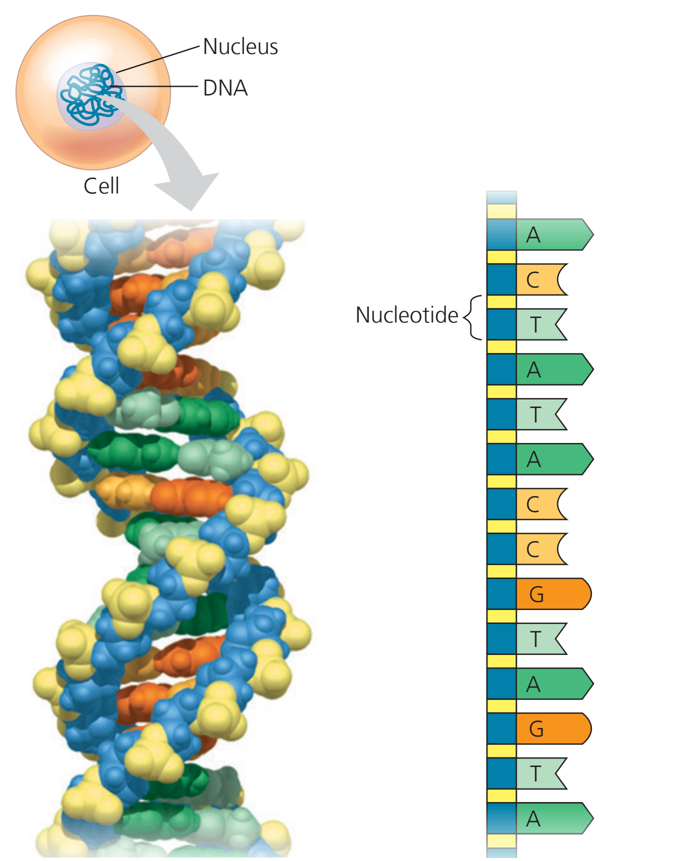


Figure 1.7 DNA: The genetic material.



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

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

in genes. The way DNA encodes information is analogous to how we arrange the letters of the alphabet into words and phrases with specific meanings. The word *rat*, for example, evokes a rodent; the words *tar* and *art*, which contain the same letters, mean very different things. We can think of nucleotides as a four-letter alphabet.

For many genes, the sequence provides the blueprint for making a protein. For instance, a given bacterial gene may specify a particular protein (an enzyme) required to break down a certain sugar molecule, while a human gene may denote a different protein (an antibody) that helps fight off infection. Overall, proteins are major players in building and maintaining the cell and carrying out its activities.

Protein-encoding genes control protein production indirectly, using a related molecule called RNA (ribonucleic acid) as an intermediary **(Figure 1.8)**. The sequence of nucleotides along a gene is transcribed into mRNA (messenger RNA), which is then translated into a linked series of protein building blocks called amino acids. Once completed, the amino acid chain forms a specific protein with a unique shape and function. The entire process by which the information in a gene directs the manufacture of a cellular product is called **gene expression**.

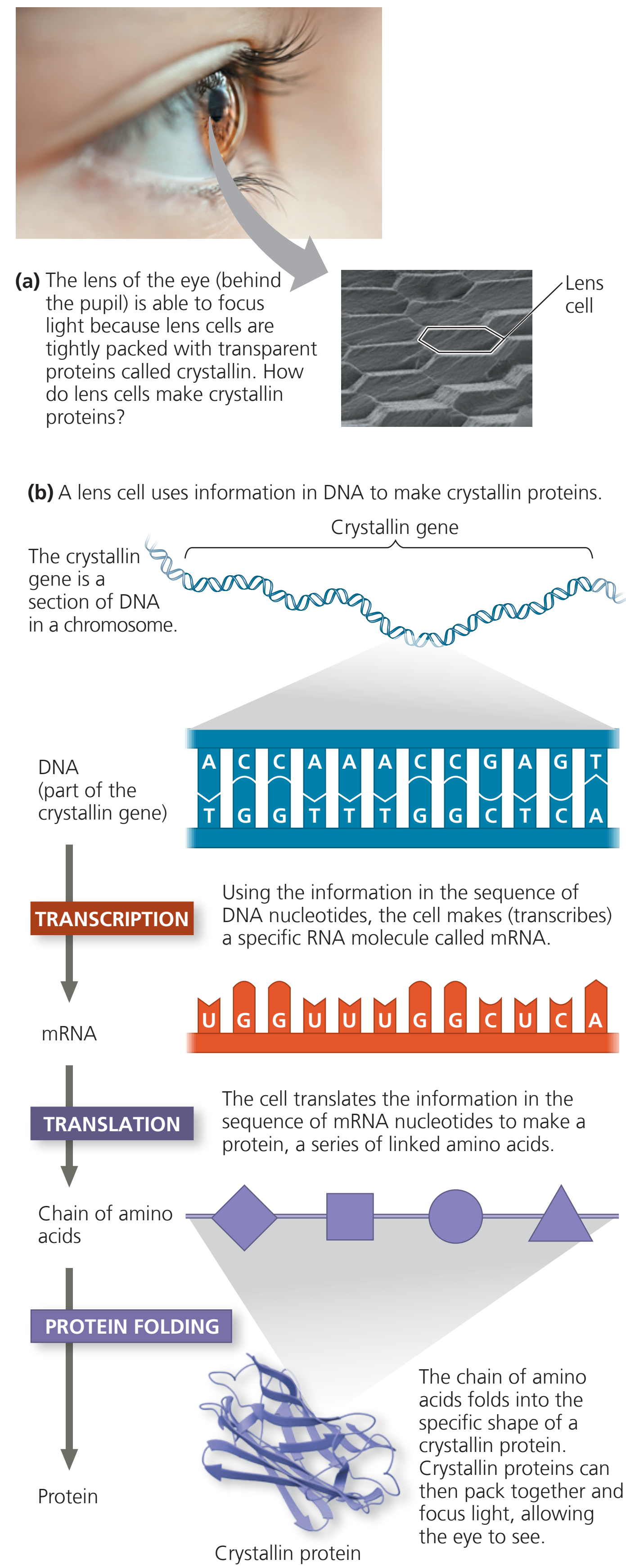
In carrying out gene expression, all forms of life employ essentially the same genetic code: A particular sequence of nucleotides says the same thing in one organism as it does in another. Differences between organisms reflect differences between their nucleotide sequences rather than between their genetic codes. This universality of the genetic code is a strong piece of evidence that all life is related. Comparing the sequences in several species for a gene that codes for a particular protein can provide valuable information both about the protein and about the relationship of the species to each other.

The mRNA molecule in Figure 1.8 is translated into a protein, but other cellular RNAs function differently. For example, we have known for decades that some types of RNA are actually components of the cellular machinery that manufactures proteins. Recently, scientists have discovered whole new classes of RNA that play other roles in the cell, such as regulating the functioning of protein-coding genes. Genes specify all of these RNAs as well, and their production is also referred to as gene expression. By carrying the instructions for making proteins and RNAs and by replicating with each cell division, DNA ensures faithful inheritance of genetic information from generation to generation.

Genomics: Large-Scale Analysis of DNA Sequences

The entire "library" of genetic instructions that an organism inherits is called its **genome**. A typical human cell has two similar sets of chromosomes, and each set has approximately 3 billion nucleotide pairs of DNA. If the one-letter abbreviations for the nucleotides of a set were written in letters the

▼ Figure 1.8 Gene expression: Cells use information encoded in a gene to synthesise a functional protein.



MB Figure Walkthrough

size of those you are now reading, the genomic text would fill about 700 biology textbooks.

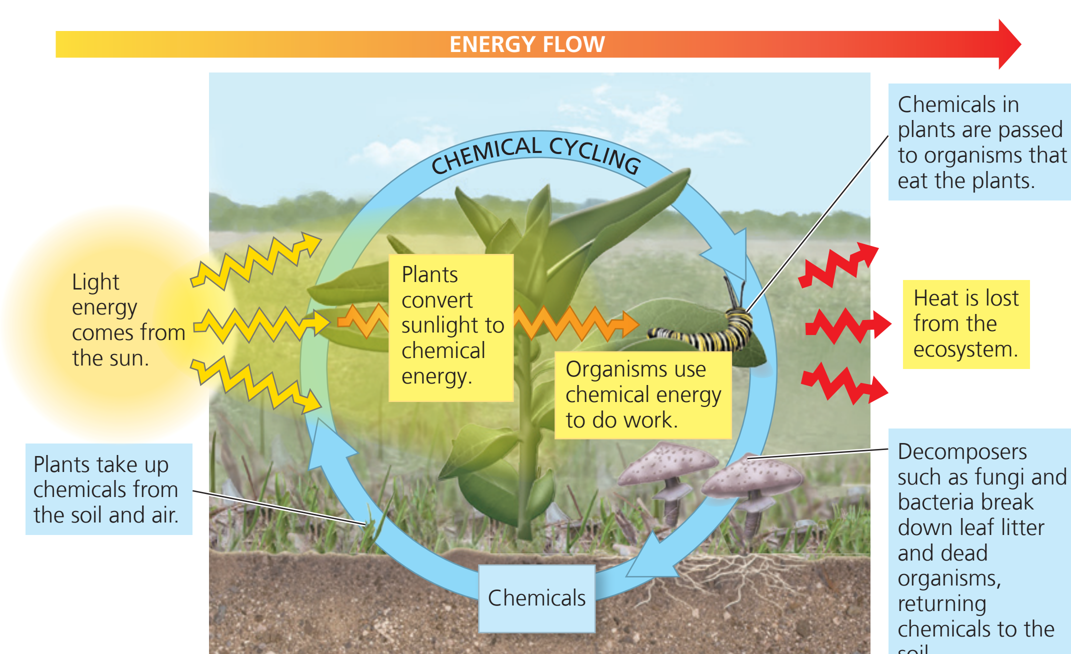
Since the early 1990s, the pace at which researchers can determine the sequence of a genome has accelerated at an astounding rate, enabled by a revolution in technology. The genome sequence—the entire sequence of nucleotides for a representative member of a species—is now known for humans and many other animals, as well as numerous plants, fungi, bacteria, and archaea. To make sense of the deluge of data from genome-sequencing projects and the growing catalogue of known gene functions, scientists are applying a systems biology approach at the cellular and molecular levels. Rather than investigating a single gene at a time, researchers study whole sets of genes (or other DNA) in one or more species—an approach called **genomics**. Likewise, the term **proteomics** refers to the study of sets of proteins and their properties. (The entire set of proteins expressed by a given cell, tissue, or organism is called a **proteome**.)

Three important research developments have made the genomic and proteomic approaches possible. One is "high-throughput" technology, tools that can analyse many biological samples very rapidly. The second major development is **bioinformatics**, the use of computational tools to store, organise, and analyse the huge volume of data that results from high-throughput methods. The third development is the formation of interdisciplinary research teams—groups of diverse specialists that may include computer scientists, mathematicians, engineers, chemists, physicists, and, of course, biologists from a variety of fields. Researchers in such teams aim to learn how the activities of all the proteins and RNAs encoded by the DNA are coordinated in cells and in whole organisms.

Theme: Life Requires the Transfer and Transformation of Energy and Matter

ENERGY AND MATTER A fundamental characteristic of living organisms is their use of energy to carry out life's activities. Moving, growing, reproducing, and the various cellular activities of life are work, and work requires energy. The input of energy, primarily from the sun, and the transformation of energy from one form to another make life possible **(Figure 1.9)**. When a plant's leaves absorb sunlight, molecules within the leaves convert the energy of sunlight to the chemical energy of food, such as sugars, in the process of photosynthesis. The chemical energy in the food molecules is then passed along by plants and other photosynthetic organisms (**producers**) to consumers. **Consumers** are organisms, such as animals, that feed on other organisms or their remains.

When an organism uses chemical energy to perform work, such as muscle contraction or cell division, some of that energy is lost to the surroundings as heat. As a result, energy *flows through* an ecosystem in one direction, usually entering as light and exiting as heat. In contrast, chemicals *cycle within* an ecosystem, where they are used and then recycled (see Figure 1.9). Chemicals that a plant absorbs from the air or soil may be incorporated into the plant's body and then passed to an animal that eats the plant. Eventually, these chemicals will be returned to the environment by decomposers such as bacteria and fungi that break down waste products, leaf litter, and the bodies of dead organisms. The chemicals are then available to be taken up by plants again, thereby completing the cycle.



➤ **Figure 1.9 Energy flow and chemical cycling.** There is a one-way flow of energy in an ecosystem: During photosynthesis, plants convert energy from sunlight to chemical energy (stored in food molecules such as sugars), which is used by plants and other organisms to do work and is eventually lost from the ecosystem as heat. In contrast, chemicals cycle between organisms and the physical environment.