



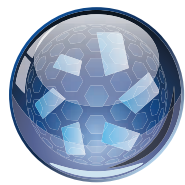
# BIOLOGY

The Unity and  
Diversity of Life



STARR  
TAGGART  
EVERS  
STARR

14<sup>TH</sup> EDITION



# MindTap™

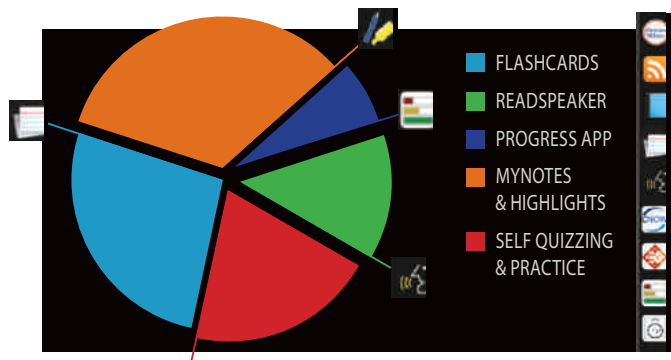
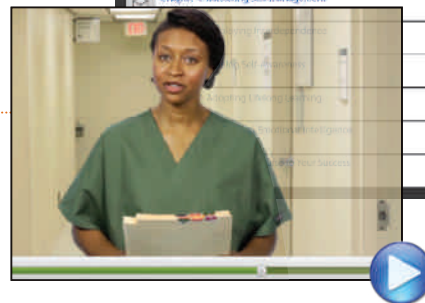
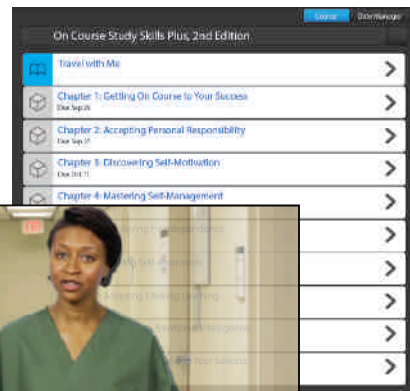
## Tap into **engagement**

MindTap empowers you to produce your best work—consistently.

MindTap is designed to help you master the material. Interactive videos, animations, and activities create a learning path designed by your instructor to guide you through the course and focus on what's important.

### MindTap delivers real-world activities and assignments

that will help you in your academic life as well as your career.

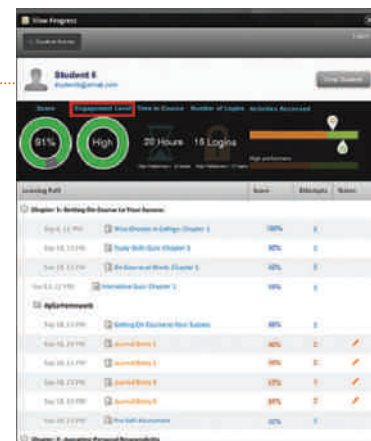


### MindTap helps you stay organized and efficient

by giving you the study tools to master the material.

### MindTap empowers and motivates

with information that shows where you stand at all times—both individually and compared to the highest performers in class.



*"MindTap was very useful – it was easy to follow and everything was right there."*

— Student, San Jose State University

*"I'm definitely more engaged because of MindTap."*

— Student, University of Central Florida

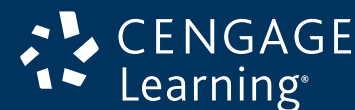
*"MindTap puts practice questions in a format that works well for me."*

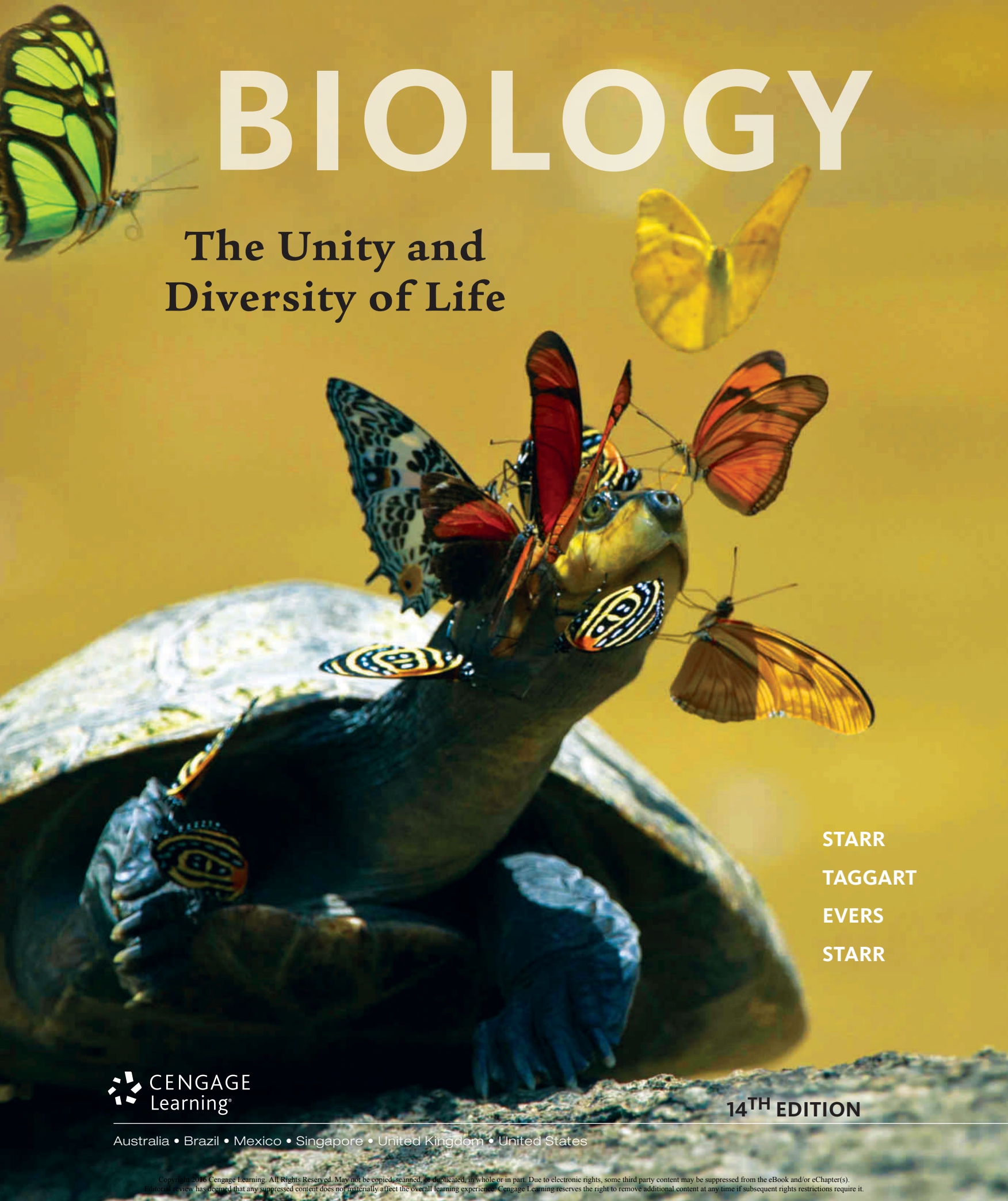
— Student, Franciscan University of Steubenville

Tap into more info at: [www.cengage.com/mindtap](http://www.cengage.com/mindtap)

Source Code: 14M-AA0105

Engaged with you.  
[www.cengage.com](http://www.cengage.com)





# BIOLOGY

## The Unity and Diversity of Life

STARR  
TAGGART  
EVERS  
STARR

 CENGAGE  
Learning®

14<sup>TH</sup> EDITION

Australia • Brazil • Mexico • Singapore • United Kingdom • United States

Copyright 2016 Cengage Learning. All Rights Reserved. May not be copied, scanned, or duplicated, in whole or in part. Due to electronic rights, some third party content may be suppressed from the eBook and/or eChapter(s). Editorial review has deemed that any suppressed content does not materially affect the overall learning experience. Cengage Learning reserves the right to remove additional content at any time if subsequent rights restrictions require it.

This is an electronic version of the print textbook. Due to electronic rights restrictions, some third party content may be suppressed. Editorial review has deemed that any suppressed content does not materially affect the overall learning experience. The publisher reserves the right to remove content from this title at any time if subsequent rights restrictions require it. For valuable information on pricing, previous editions, changes to current editions, and alternate formats, please visit [www.cengage.com/highered](http://www.cengage.com/highered) to search by ISBN#, author, title, or keyword for materials in your areas of interest.

***Biology: The Unity and Diversity of Life,***  
**Fourteenth Edition**

**Cecie Starr, Ralph Taggart, Christine Evers,  
Lisa Starr**

Product Director: Mary Finch

Senior Product Team Manager: Yolanda Cossio

Senior Product Manager: Peggy Williams

Associate Content Developers: Kellie Petruzzelli,  
Casey Lozier

Product Assistant: Victor Luu

Media Developer: Lauren Oliveira

Senior Market Development Manager:  
Tom Ziolkowski

Content Project Manager: Harold Humphrey

Senior Art Directors: John Walker, Bethany Casey

Manufacturing Planner: Karen Hunt

Production Service: Grace Davidson & Associates

Photo Researcher: Cheryl DuBois, PreMedia Global

Text Researcher: Kristine Janssens,  
PreMedia Global

Copy Editor: Anita Wagner Heuftle

Illustrators: Lisa Starr, Gary Head,  
ScEYEnce Studios

Text Designer: Lisa Starr

Cover Designer: Bethany Casey

Cover and Title Page Image:

© Pete Oxford/Minden Pictures

Butterflies sip the tears of a yellow-spotted river turtle sunning itself in Yasuní National Park, Ecuador. Turtle tears supply the butterflies with sodium, an essential nutrient missing from their flower nectar diet in the Amazon rainforest.

Butterflies are almost never observed sipping turtle tears outside of this small region, which is famous for having one of the most diverse assortments of species in the world. Currently, oil drilling operations are destroying the forest and wildlife in the park.

Compositor: Lachina Publishing Services

© 2016, 2013 Cengage Learning

WCN: 02-200-203

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced, transmitted, stored or used in any form or by any means graphic, electronic, or mechanical, including but not limited to photocopying, recording, scanning, digitizing, taping, Web distribution, information networks, or information storage and retrieval systems, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the publisher.

For product information and technology assistance, contact us at  
**Cengage Learning Customer & Sales Support, 1-800-354-9706.**

For permission to use material from this text or product,  
submit all requests online at [www.cengage.com/permissions](http://www.cengage.com/permissions).

Further permissions questions can be emailed to  
[permissionrequest@cengage.com](mailto:permissionrequest@cengage.com).

Library of Congress Control Number: 2014944585

Student Edition:

ISBN-13: 978-1-305-07395-1

ISBN-10: 1-305-07395-9

Loose-leaf Edition:

ISBN-13: 978-1-305-25131-1

ISBN-10: 1-305-25131-8

**Cengage Learning**

20 Channel Center Street

Boston, MA 02210

USA

Cengage Learning is a leading provider of customized learning solutions with office locations around the globe, including Singapore, the United Kingdom, Australia, Mexico, Brazil, and Japan. Locate your local office at:

[www.cengage.com/global](http://www.cengage.com/global).

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

To learn more about Cengage Learning Solutions, visit [www.cengage.com](http://www.cengage.com).

Purchase any of our products at your local college store or at our preferred online store [www.cengagebrain.com](http://www.cengagebrain.com).

Printed in Canada

Print Number: 01 Print Year: 2014

# Contents in Brief

## INTRODUCTION

---

- 1 Invitation to Biology

## UNIT I PRINCIPLES OF CELLULAR LIFE

---

- 2 Life's Chemical Basis
- 3 Molecules of Life
- 4 Cell Structure
- 5 Ground Rules of Metabolism
- 6 Where It Starts—Photosynthesis
- 7 How Cells Release Chemical Energy

## UNIT II GENETICS

---

- 8 DNA Structure and Function
- 9 From DNA to Protein
- 10 Control of Gene Expression
- 11 How Cells Reproduce
- 12 Meiosis and Sexual Reproduction
- 13 Observing Patterns in Inherited Traits
- 14 Chromosomes and Human Inheritance
- 15 Studying and Manipulating Genomes

## UNIT III PRINCIPLES OF EVOLUTION

---

- 16 Evidence of Evolution
- 17 Processes of Evolution
- 18 Organizing Information About Species
- 19 Life's Origin and Early Evolution

## UNIT IV EVOLUTION AND BIODIVERSITY

---

- 20 Viruses, Bacteria, and Archaea
- 21 Protists—The Simplest Eukaryotes
- 22 The Land Plants
- 23 Fungi
- 24 Animal Evolution—The Invertebrates
- 25 Animal Evolution—The Chordates
- 26 Human Evolution



## UNIT V HOW PLANTS WORK

---

- 27 Plant Tissues
- 28 Plant Nutrition and Transport
- 29 Life Cycles of Flowering Plants
- 30 Communication Strategies in Plants

## UNIT VI HOW ANIMALS WORK

---

- 31 Animal Tissues and Organ Systems
- 32 Neural Control
- 33 Sensory Perception
- 34 Endocrine Control
- 35 Structural Support and Movement
- 36 Circulation
- 37 Immunity
- 38 Respiration
- 39 Digestion and Nutrition
- 40 Maintaining the Internal Environment
- 41 Animal Reproductive Systems
- 42 Animal Development
- 43 Animal Behavior

## UNIT VII PRINCIPLES OF ECOLOGY

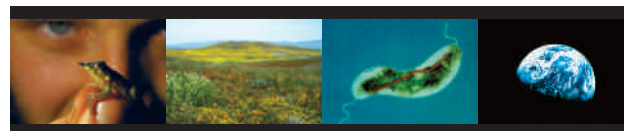
---

- 44 Population Ecology
- 45 Community Ecology
- 46 Ecosystems
- 47 The Biosphere
- 48 Human Impacts on the Biosphere

# Detailed Contents

## INTRODUCTION

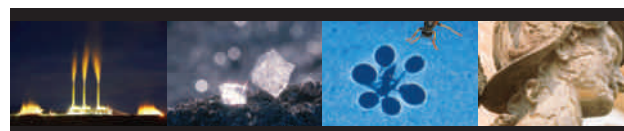
### 1 Invitation to Biology



- 1.1** The Secret Life of Earth 3
  - 1.2** Life Is More Than the Sum of Its Parts 4
  - 1.3** How Living Things Are Alike 6
    - Organisms Require Energy and Nutrients 6
    - Organisms Sense and Respond to Change 7
    - Organisms Use DNA 7
  - 1.4** How Living Things Differ 8
  - 1.5** Organizing Information About Species 10
    - A Rose by Any Other Name . . . 10
  - 1.6** The Science of Nature 12
    - Thinking About Thinking 12
    - The Scientific Method 12
  - 1.7** Examples of Experiments in Biology 14
    - Potato Chips and Stomachaches 14
    - Butterflies and Birds 14
  - 1.8** Analyzing Experimental Results 16
    - Sampling Error 16
    - Bias in Interpreting Results 17
  - 1.9** The Nature of Science 18
    - The Limits of Science 18
- The Secret Life of Earth (revisited) 19

## UNIT I PRINCIPLES OF CELLULAR LIFE

### 2 Life's Chemical Basis



- 2.1** Mercury Rising 23
- 2.2** Start With Atoms 24
  - Isotopes and Radioisotopes 24

- 2.3** Why Electrons Matter 26  
About Vacancies 27

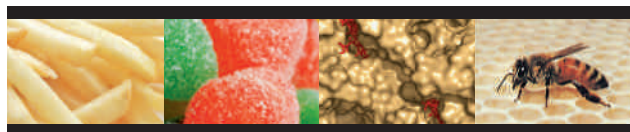
- 2.4** Chemical Bonds: From Atoms to Molecules 28  
Ionic Bonds 28  
Covalent Bonds 28

- 2.5** Hydrogen Bonds and Water 30  
Hydrogen Bonding in Water 30  
Water's Special Properties 30

- 2.6** Acids and Bases 32

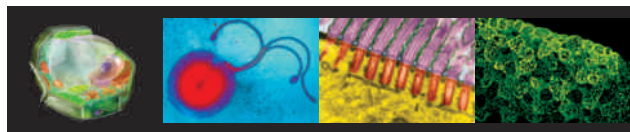
Mercury Rising (revisited) 33

### 3 Molecules of Life



- 3.1** Fear of Frying 37
- 3.2** Organic Molecules 38  
Carbon: The Stuff of Life 38  
Modeling Organic Molecules 38
- 3.3** Molecules of Life—From Structure to Function 40  
Functional Groups 40  
What Cells Do to Organic Compounds 40
- 3.4** Carbohydrates 42  
Carbohydrates in Biological Systems 42
- 3.5** Lipids 44  
Lipids in Biological Systems 44
- 3.6** Proteins 46
- 3.7** Why Is Protein Structure So Important? 48
- 3.8** Nucleic Acids 49
- Fear of Frying (revisited) 49

### 4 Cell Structure



- 4.1** Food for Thought 53

- 4.2** What Is a Cell 54  
Cell Theory 54  
Components of All Cells 54  
Constraints on Cell Size 55

- 4.3** How Do We See Cells? 56

- 4.4** Introducing Prokaryotes 58  
Biofilms 59

- 4.5** Introducing Eukaryotic Cells 60

- 4.6** The Nucleus 62  
Chromatin 62  
The Nuclear Envelope 62  
The Nucleolus 63

- 4.7** The Endomembrane System 64

- 4.8** Mitochondria 66

- 4.9** Chloroplasts and Other Plastids 67

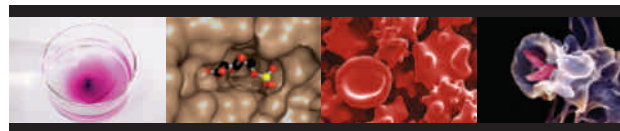
- 4.10** The Cytoskeleton 68

- 4.11** Cell Surface Specializations 70  
Cell Matrices 70  
Cell Junctions 70

- 4.12** The Nature of Life 72

Food for Thought (revisited) 73

### 5 Ground Rules of Metabolism



- 5.1** A Toast to Alcohol Dehydrogenase 77
- 5.2** Energy in the World of Life 78  
Energy Disperses 78  
Energy's One-Way Flow 78
- 5.3** Energy in the Molecules of Life 80  
Chemical Bond Energy 80  
Why Earth Does Not Go Up in Flames 80  
Energy In, Energy Out 81
- 5.4** How Enzymes Work 82  
The Need for Speed 82  
The Transition State 82  
Enzyme Activity 83



## Detailed Contents (continued)

### 5.5 Metabolism—Organized, Enzyme-Mediated Reactions 84

Controls Over Metabolism 84

Electron Transfers 84

### 5.6 Cofactors in Metabolic Pathways 86

ATP—A Special Coenzyme 86

### 5.7 A Closer Look at Cell Membranes 88

The Fluid Mosaic Model 88

Proteins Add Function 88

### 5.8 Diffusion and Membranes 90

Semipermeable Membranes 90

Turgor 91

### 5.9 Membrane Transport Mechanisms 92

Transport Protein Specificity 92

Facilitated Diffusion 92

Active Transport 93

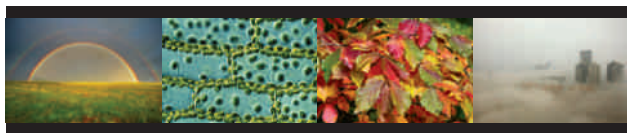
### 5.10 Membrane Trafficking 94

Endocytosis and Exocytosis 94

Recycling Membrane 95

A Toast to Alcohol Dehydrogenase (revisited) 96

## 6 Where It Starts—Photosynthesis



### 6.1 Biofuels 101

### 6.2 Sunlight as an Energy Source 102

Properties of Light 102

Pigments: The Rainbow Catchers 102

### 6.3 Exploring the Rainbow 104

### 6.4 Overview of Photosynthesis 105

### 6.5 Light-Dependent Reactions 106

The Noncyclic Pathway 106

The Cyclic Pathway 107

### 6.6 The Light-Independent Reactions 108

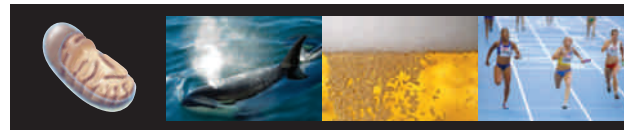
Energy Flow in Photosynthesis 108

Light-Independent Reactions 108

### 6.7 Adaptations: Alternative Carbon-Fixing Pathways 110

Biofuels (revisited) 112

## 7 How Cells Release Chemical Energy



### 7.1 Risky Business 117

### 7.2 Overview of Carbohydrate Breakdown Pathways 118

### 7.3 Glycolysis—Sugar Breakdown Begins 120

### 7.4 Second Stage of Aerobic Respiration 122

Acetyl-CoA Formation 122

The Krebs Cycle 122

### 7.5 Aerobic Respiration's Big Energy Payoff 124

### 7.6 Fermentation 126

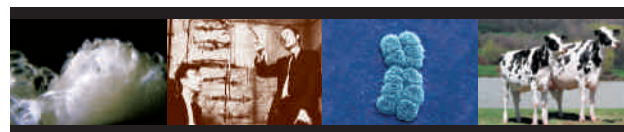
### 7.7 Alternative Energy Sources in Food 128

Energy From Dietary Molecules 128

Risky Business (revisited) 129

## UNIT II GENETICS

## 8 DNA Structure and Function



### 8.1 A Hero Dog's Golden Clones 133

### 8.2 The Discovery of DNA's Function 134

### 8.3 The Discovery of DNA's Structure 136

Building Blocks of DNA 136

DNA's Base Sequence 137

### 8.4 Eukaryotic Chromosomes 138

Chromosome Number and Type 139

### 8.5 DNA Replication 140

### 8.6 Mutations: Cause and Effect 142

Replication Errors 142

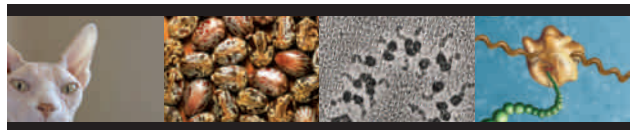
Agents of DNA Damage 142

Rosalind Franklin, X-Rays, and Cancer 143

### 8.7 Cloning Adult Animals 144

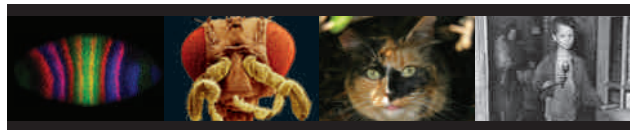
A Hero Dog's Golden Clones (revisited) 145

## 9 From DNA to Protein



- 9.1** Ricin, RIP 149
- 9.2** DNA, RNA, and Gene Expression 150
  - DNA to RNA 150
  - RNA to Protein 150
- 9.3** Transcription: DNA to RNA 152
  - Post-Transcriptional Modifications 153
- 9.4** RNA and the Genetic Code 154
- 9.5** Translation: RNA to Protein 156
- 9.6** Mutated Genes and Their Protein Products 158
  - Ricin, RIP (revisited) 160

## 10 Control of Gene Expression

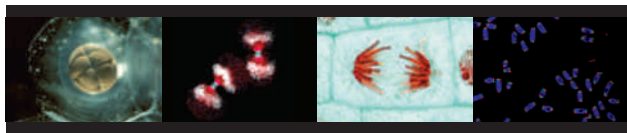


- 10.1** Between You and Eternity 163
- 10.2** Switching Genes On and Off 164
  - Gene Expression Control 164
- 10.3** Master Genes 166
  - Homeotic Genes 166
- 10.4** Examples of Gene Control in Eukaryotes 168
  - X Marks the Spot 168
  - Male Sex Determination in Humans 168
  - Flower Formation 169
- 10.5** Examples of Gene Control in Prokaryotes 170
  - The *lac* Operon 170
  - Lactose Intolerance 171
  - Riboswitches 171
- 10.6** Epigenetics 172
  - Between You and Eternity (revisited) 173



# Detailed Contents (continued)

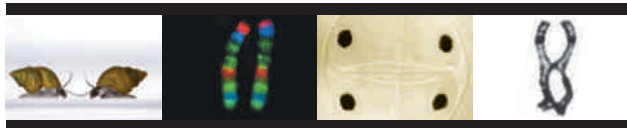
## 11 How Cells Reproduce



- 11.1** Henrietta's Immortal Cells 177
- 11.2** Multiplication by Division 178
  - Controls Over the Cell Cycle 179
- 11.3** A Closer Look at Mitosis 180
- 11.4** Cytokinesis: Division of Cytoplasm 182
- 11.5** Marking Time With Telomeres 183
- 11.6** When Mitosis Becomes Pathological 184
  - Cancer 184

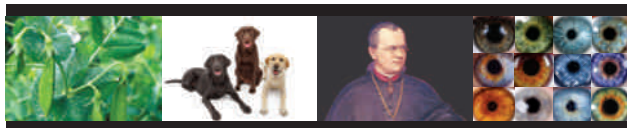
Henrietta's Immortal Cells (revisited) 186

## 12 Meiosis and Sexual Reproduction



- 12.1** Why Sex? 189
- 12.2** Meiosis in Sexual Reproduction 190
  - Introducing Alleles 190
  - Meiosis Halves the Chromosome Number 190
  - Fertilization Restores Chromosome Number 191
- 12.3** Visual Tour of Meiosis 192
- 12.4** How Meiosis Introduces Variations in Traits 194
  - Crossing Over 194
  - Chromosome Segregation 194
- 12.5** Mitosis and Meiosis—An Ancestral Connection? 196
  - Why Sex? (revisited) 197

## 13 Observing Patterns in Inherited Traits



- 13.1** Menacing Mucus 201

- 13.2** Mendel, Pea Plants, and Inheritance Patterns 202
  - Mendel's Experiments 202
  - Inheritance in Modern Terms 202

- 13.3** Mendel's Law of Segregation 204

- 13.4** Mendel's Law of Independent Assortment 206
  - The Contribution of Crossovers 206

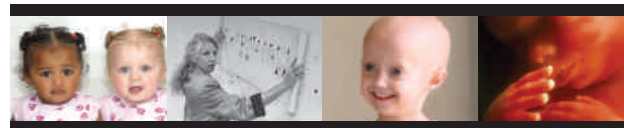
- 13.5** Beyond Simple Dominance 208
  - Codominance 208
  - Incomplete Dominance 208
  - Epistasis 209
  - Pleiotropy 209

- 13.6** Nature and Nurture 210
  - Some Environmental Effects 210

- 13.7** Complex Variation in Traits 212
  - Continuous Variation 212

Menacing Mucus (revisited) 213

## 14 Chromosomes and Human Inheritance



- 14.1** Shades of Skin 217
- 14.2** Human Chromosomes 218
  - Types of Genetic Variation 218
- 14.3** Examples of Autosomal Inheritance Patterns 220
  - The Autosomal Dominant Pattern 220
  - The Autosomal Recessive Pattern 221
- 14.4** Examples of X-Linked Inheritance Patterns 222
  - The X-Linked Recessive Pattern 222
- 14.5** Heritable Changes in Chromosome Structure 224
  - Types of Chromosomal Change 224
  - Chromosome Changes in Evolution 225
- 14.6** Heritable Changes in Chromosome Number 226
  - Autosomal Aneuploidy and Down Syndrome 226
  - Sex Chromosome Aneuploidy 226
- 14.7** Genetic Screening 228
  - Shades of Skin (revisited) 229

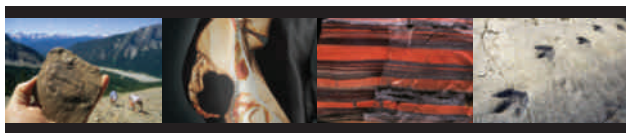
## 15 Studying and Manipulating Genomes



- 15.1** Personal Genetic Testing 233
  - 15.2** Cloning DNA 234
    - Cut and Paste 234
    - cDNA Cloning 235
  - 15.3** Isolating Genes 236
    - DNA Libraries 236
    - PCR 236
  - 15.4** DNA Sequencing 238
    - The Human Genome Project 239
  - 15.5** Genomics 240
    - DNA Profiling 240
  - 15.6** Genetic Engineering 242
  - 15.7** Designer Plants 242
  - 15.8** Biotech Barnyards 244
    - Knockouts and Organ Factories 245
  - 15.9** Safety Issues 245
  - 15.10** Genetically Modified Humans 246
    - Gene Therapy 246
    - Eugenics 247
- Personal Genetic Testing (revisited) 247

### UNIT III PRINCIPLES OF EVOLUTION

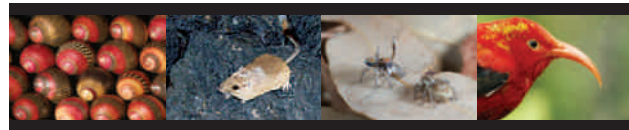
## 16 Evidence of Evolution



- 16.1** Reflections of a Distant Past 251
- 16.2** Early Beliefs, Confounding Discoveries 252
- 16.3** A Flurry of New Theories 254
  - Squeezing New Evidence Into Old Beliefs 254
  - Darwin and the HMS *Beagle* 254

- 16.4** Darwin, Wallace, and Natural Selection 256
  - A Key Insight—Variation in Traits 256
  - Great Minds Think Alike 257
- 16.5** Fossils: Evidence of Ancient Life 258
  - The Fossil Record 259
- 16.6** Filling In Pieces of the Puzzle 260
  - Radiometric Dating 260
  - Missing Links 261
- 16.7** Drifting Continents, Changing Seas 262
- 16.8** Putting Time Into Perspective 264
  - Reflections of a Distant Past (revisited) 266

## 17 Processes of Evolution



- 17.1** Superbug Farms 269
- 17.2** Individuals Don't Evolve, Populations Do 270
  - Alleles in Populations 270
  - An Evolutionary View of Mutations 270
  - Allele Frequencies 271
- 17.3** Genetic Equilibrium 272
  - Applying the Hardy–Weinberg Law 272
  - Real-World Situations 273
- 17.4** Patterns of Natural Selection 273
- 17.5** Directional Selection 274
  - Examples of Directional Selection 274
- 17.6** Stabilizing and Disruptive Selection 276
  - Stabilizing Selection 276
  - Disruptive Selection 277
- 17.7** Fostering Diversity 278
  - Survival of the Sexiest 278
  - Maintaining Multiple Alleles 278
- 17.8** Genetic Drift and Gene Flow 280
  - Genetic Drift 280
  - Bottlenecks and the Founder Effect 280
  - Gene Flow 281
- 17.9** Reproductive Isolation 282

## Detailed Contents (continued)

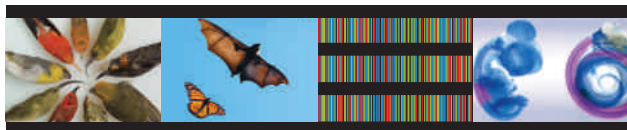
- 17.10** Allopatric Speciation 284  
Speciation in Archipelagos 284

- 17.11** Other Speciation Models 286  
Sympatric Speciation 286  
Parapatric Speciation 287

- 17.12** Macroevolution 288  
Evolutionary Theory 289

Superbug Farms (revisited) 289

### 18 Organizing Information About Species



- 18.1** Bye Bye Birdie 293

- 18.2** Phylogeny 294  
Cladistics 295

- 18.3** Comparing Form and Function 296  
Morphological Divergence 296  
Morphological Convergence 296

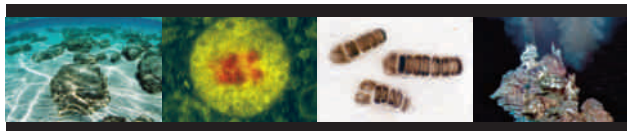
- 18.4** Comparing Biochemistry 298  
DNA and Protein Sequence Comparisons 298

- 18.5** Comparing Patterns of Animal Development 300

- 18.6** Applications of Phylogeny Research 301  
Conservation Biology 301  
Medical Research 301

Bye Bye Birdie (revisited) 302

### 19 Life's Origin and Early Evolution



- 19.1** Looking for Life 305

- 19.2** The Early Earth 306  
Origin of the Universe and Earth 306  
Conditions on the Early Earth 306

- 19.3** Organic Monomers Form 307  
Organic Molecules From Inorganic Precursors 307  
Sources of Life's First Building Blocks 307

- 19.4** From Polymers to Protocells 308  
Properties of Cells 308  
Origin of Metabolism 308  
Origin of the Genome 308  
Origin of the Plasma Membrane 309

- 19.5** Life's Early Evolution 310  
The Common Ancestor of All Life 310  
Looking for Evidence of Early Life 310  
The Oldest Fossil Cells 310  
Changes in the Air 311  
Rise of the Eukaryotes 311

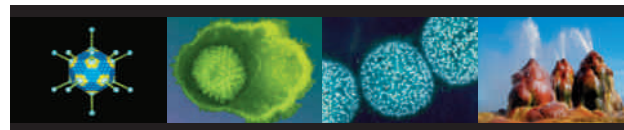
- 19.6** Origin and Evolution of Eukaryotes 312  
Origin of the Nucleus 312  
Origin of Mitochondria and Chloroplasts 312  
Eukaryotic Divergence 313

- 19.7** Time Line for Life's Origin and Evolution 314

Looking for Life (revisited) 316

## UNIT IV EVOLUTION AND BIODIVERSITY

### 20 Viruses, Bacteria, and Archaea



- 20.1** Evolution of a Disease 319

- 20.2** Viruses and Viroids 320  
Viral Structure 320  
Origin and Ecological Role of Viruses 321  
Viroids 321

- 20.3** Viral Replication 322  
Overview of Viral Replication 322  
Bacteriophage Replication 322  
Replication of HIV 322

- 20.4** Viruses as Human Pathogens 324  
The Threat of Infectious Disease 324  
Common Viral Diseases 324  
Emerging Viral Diseases 324  
Viral Mutation and Reassortment 324

- 20.5** Shared Traits of Prokaryotes 326  
Structural Traits 326  
Reproduction and Gene Transfers 326

## 20.6 Factors in the Success of Prokaryotes 328

- Diverse Modes of Nutrition 328
- Aerobes and Anaerobes 328
- Dormant Resting Structures 328
- Investigating Species Diversity 329

## 20.7 A Sample of Bacterial Diversity 330

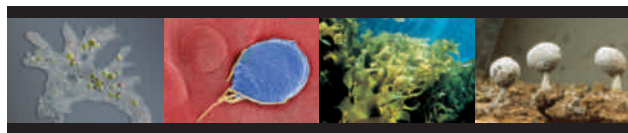
- Heat Lovers 330
- Oxygen-Producing Cyanobacteria 330
- Highly Diverse Proteobacteria 330
- Thick-Walled, Gram-Positive Bacteria 331
- The Tiny Spirochetes and Chlamydias 331

## 20.8 Archaea 332

- Discovery of the Third Domain 332
- Here, There, Everywhere 332

Evolution of a Disease (revisited) 333

## 21 Protists—The Simplest Eukaryotes



### 21.1 Malaria: From Tutankhamun to Today 337

### 21.2 A Collection of Lineages 338

- Classification and Phylogeny 338
- Cells, Colonies, and Multicellular Organisms 338
- Modes of Nutrition 338
- Diverse Life Cycles 339

### 21.3 Flagellated Protozoans 340

- Anaerobic Flagellates 340
- Trypanosomes and Other Kinetoplastids 341
- Euglenoids 341

### 21.4 Foraminifera and Radiolarians 342

### 21.5 Ciliates 343

### 21.6 Dinoflagellates 344

### 21.7 Apicomplexans 345

### 21.8 Stramenopiles 346

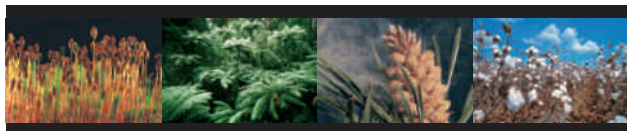
- Diatoms 346
- Brown Algae 347
- Water Molds 347



## Detailed Contents (continued)

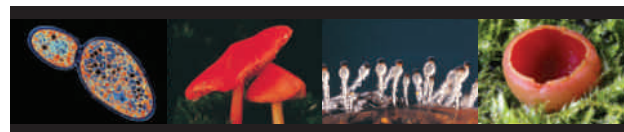
- 21.9** Red Algae and Green Algae 348
    - Red Algae 348
    - Green Algae 348
  - 21.10** Amoebozoans and Choanoflagellates 350
    - Amoebozoans 350
    - Choanoflagellates 351
- Malaria: From Tutankhamun to Today (revisited) 351

## 22 The Land Plants



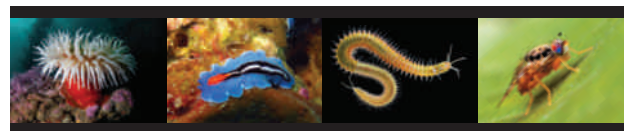
- 22.1** Saving Seeds 355
  - 22.2** Plant Ancestry and Diversity 356
    - From Algal Ancestors to Embryophytes 356
    - An Adaptive Radiation on Land 356
  - 22.3** Evolutionary Trends Among Plants 358
    - From Haploid to Diploid Dominance 358
    - Structural Adaptations 358
    - Pollen and Seeds 359
  - 22.4** Bryophytes 360
    - Mosses 360
    - Liverworts 361
    - Hornworts 361
  - 22.5** Seedless Vascular Plants 362
    - Club Mosses 362
    - Whisk Ferns and Horsetails 362
    - Ferns 362
  - 22.6** History of the Vascular Plants 364
    - From Tiny Branchers to Coal Forests 364
    - Rise of the Seed Plants 364
  - 22.7** Gymnosperms 366
    - Conifers 366
    - Lesser-Known Lineages 367
  - 22.8** Angiosperms—The Flowering Plants 368
    - The Angiosperm Life Cycle 369
    - Factors Contributing to Angiosperm Success 369
  - 22.9** Angiosperm Diversity and Importance 370
    - Angiosperm Lineages 370
    - Ecological and Economic Importance 370
- Saving Seeds (revisited) 371

## 23 Fungi



- 23.1** High-Flying Fungi 375
  - 23.2** Fungal Traits and Classification 376
    - Structure and Function 376
    - Life Cycles 377
  - 23.3** Flagellated Fungi 377
  - 23.4** Zygote Fungi and Related Groups 378
    - Zygote Fungi 378
    - Microsporidia—Intracellular Parasites 379
    - Glomeromycetes—Partners of Plants 379
  - 23.5** Sac Fungi—Ascomycetes 380
    - Life Cycles 380
    - Diversity 380
    - Human Uses of Sac Fungi 380
  - 23.6** Club Fungi—Basidiomycetes 382
    - Life Cycle 382
    - Ecology 382
  - 23.7** Ecological Roles of Fungi 384
    - Fungi as Decomposers 384
    - Fungal Partnerships 384
    - Fungal Parasites and Pathogens 385
- High-Flying Fungi (revisited) 385

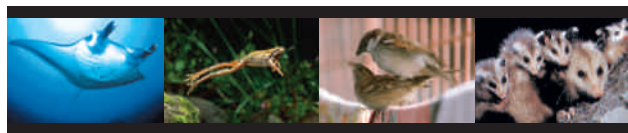
## 24 Animal Evolution—The Invertebrates



- 24.1** Medicines From the Sea 389
- 24.2** Animal Traits and Body Plans 390
  - What Is an Animal? 390
  - Variation in Animal Body Plans 390
- 24.3** Animal Origins and Adaptive Radiation 392
  - Colonial Origins 392
  - Early Animals 392
  - The Cambrian Explosion 392
- 24.4** Sponges 393

- 24.5** Cnidarians—Predators With Stinging Cells 394  
 Body Plans 394  
 Diversity and Life Cycles 394
- 24.6** Flatworms—Simple Organ Systems 396  
 Free-Living Flatworms 396  
 Parasitic Flatworms 397
- 24.7** Annelids—Segmented Worms 398  
 The Marine Polychaetes 398  
 Leeches—Bloodsuckers and Others 398  
 The Earthworm—An Oligochaete 398
- 24.8** Mollusks—Animals With a Mantle 400  
 General Characteristics 400  
 Mollusk Diversity 400
- 24.9** Rotifers and Tardigrades—Tiny and Tough 402
- 24.10** Roundworms—Unsegmented Worms That Molt 403
- 24.11** Arthropods—Molting Animals With Jointed Legs 404  
 Key Arthropod Adaptations 404
- 24.12** Chelicerates—Spiders and Their Relatives 405
- 24.13** Myriapods 406
- 24.14** Crustaceans 406
- 24.15** Insects—Diverse and Abundant 408  
 Characteristic Features 408  
 The Importance of Insects 408
- 24.16** The Spiny-Skinned Echinoderms 410  
 The Protostome–Deuterostome Split 410  
 Echinoderm Characteristics and Body Plan 410  
 Echinoderm Diversity 410
- Medicines From the Sea (revisited) 411

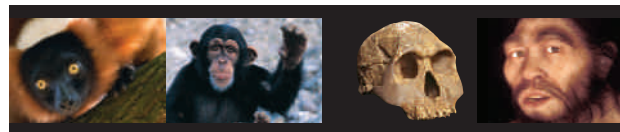
## 25 Animal Evolution—The Chordates



- 25.1** Very Early Birds 415
- 25.2** Chordate Traits and Evolutionary Trends 416  
 Chordate Characteristics 416  
 Invertebrate Chordates 416  
 Overview of Chordate Evolution 416
- 25.3** Jawless Fishes 418
- 25.4** Evolution of Jawed Fishes 419

- 25.5** Modern Jawed Fishes 420  
 Cartilaginous Fishes 420  
 Bony Fishes 420
- 25.6** Amphibians—First Tetrapods on Land 422  
 Adapting to Life on Land 422  
 Modern Amphibians 422  
 Declining Diversity 423
- 25.7** The Amniote Evolution 424
- 25.8** Nonbird Reptiles 425
- 25.9** Birds—The Feathered Ones 426  
 General Characteristics 426  
 Avian Diversity 427
- 25.10** Mammals—Milk Makers 428  
 Mammalian Traits 428  
 Mammalian Origins and Diversification 428
- 25.11** Modern Mammalian Diversity 430  
 Egg-Laying Monotremes 430  
 Marsupials 430  
 Placental Mammals 430
- Very Early Birds (revisited) 431

## 26 Human Evolution



- 26.1** A Bit of a Neanderthal 435
- 26.2** Primates: Our Order 436  
 Primate Characteristics 436  
 Origins and Early Branchings 436
- 26.3** The Apes 438  
 Hominoid Origins and Divergences 438  
 Modern Apes 438  
 A Human–Ape Comparison 439
- 26.4** Rise of the Hominins 440  
 Early Proposed Hominins 440  
 Australopiths 440  
 Factors Favoring Bipedalism 441
- 26.5** Early Humans 442  
 Classifying Fossils—Lumpers and Splitters 442  
*Homo habilis* 442  
*Homo erectus* 442  
 Early Culture 442



## Detailed Contents (continued)

- 26.6** Recent Human Lineages 444
  - Origin and Dispersal of *Homo Sapiens* 444
  - Other Recent *Homo* Species 444
- A Bit of a Neanderthal (revisited) 445

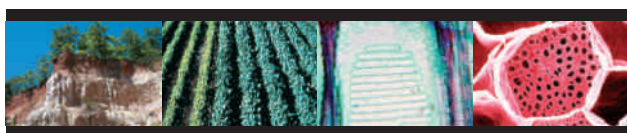
### UNIT V HOW PLANTS WORK

## 27 Plant Tissues



- 27.1** Carbon Sequestration 449
- 27.2** The Plant Body 450
- 27.3** Plant Tissues 452
- 27.4** Stems 454
  - Internal Structure 454
  - Variations on a Stem 454
- 27.5** Leaves 456
  - Internal Structure 456
- 27.6** Roots 458
  - Internal Structure 458
- 27.7** Primary Growth 460
  - Primary Growth in Shoots 460
  - Primary Growth in Roots 461
- 27.8** Secondary Growth 462
- 27.9** Tree Rings and Old Secrets 464
  - Carbon Sequestration (revisited) 465

## 28 Plant Nutrition and Transport

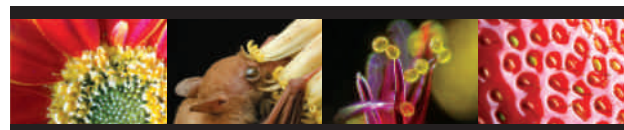


- 28.1** Leafy Cleanup 469
- 28.2** Plant Nutrients and Availability in Soil 470
  - Properties of Soil 470
  - How Soils Change 471
- 28.3** Roots Adaptations for Nutrient Uptake 472
  - The Function of Endodermis 472
  - Mutualisms 473

- 28.4** Water Movement Inside Plants 474
  - Cohesion–Tension Theory 474
- 28.5** Water-Conserving Adaptations of Stems and Leaves 476
  - How Stomata Work 476

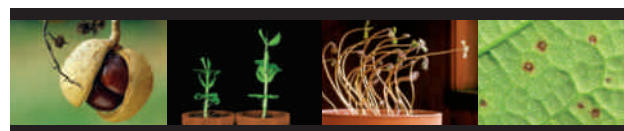
- 28.6** Movement of Organic Compounds in Plants 478
  - Leafy Cleanup (revisited) 479

## 29 Life Cycles of Flowering Plants



- 29.1** Plight of the Honeybee 483
- 29.2** Reproductive Structures 484
  - Diversity of Floral Structure 485
- 29.3** Flowers and Their Pollinators 486
- 29.4** A New Generation Begins 488
- 29.5** Flower Sex 490
- 29.6** Seed Formation 491
- 29.7** Fruits 492
- 29.8** Early Development 494
  - Breaking Dormancy 494
  - After Germination 494
- 29.9** Asexual Reproduction of Flowering Plants 496
  - Agricultural Applications 496
  - Plight of the Honeybee (revisited) 497

## 30 Communication Strategies in Plants



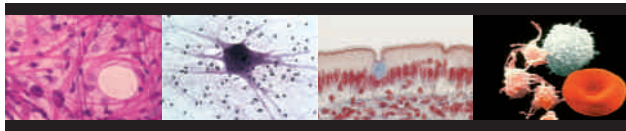
- 30.1** Prescription: Chocolate 501
- 30.2** Introduction to Plant Hormones 502
  - Chemical Signaling in Plants 502
- 30.3** Auxin: The Master Growth Hormone 504
  - Polar Transport 504
- 30.4** Cytokinin 506

- 30.5** Gibberellin 507
- 30.6** Abscisic Acid 508
- 30.7** Ethylene 509
- 30.8** Tropisms 510
- 30.9** Sensing Recurring Environmental Change 512
  - Daily Change 512
  - Seasonal Change 512
- 30.10** Responses to Stress 514

Prescription: Chocolate (revisited) 515

## UNIT VI HOW ANIMALS WORK

### **31** Animal Tissues and Organ Systems



- 31.1** Stem Cells—It's All About Potential 519
- 31.2** Organization of Animal Bodies 520
  - Levels of Organization 520
  - The Internal Environment 520
  - Evolution of Animal Structure 521
- 31.3** Epithelial Tissue 522
  - General Characteristics 522
  - Variations in Structure and Function 522
  - Epithelial Cell Secretions 523
  - Carcinomas—Epithelial Cell Cancers 523
- 31.4** Connective Tissues 524
  - General Characteristics 524
  - Types of Connective Tissue 524
- 31.5** Muscle Tissues 526
  - Skeletal Muscle Tissue 526
  - Cardiac Muscle Tissue 526
  - Smooth Muscle Tissue 526
- 31.6** Nervous Tissue 527
- 31.7** Organ Systems 528
- 31.8** Human Integumentary System 530
  - Structure of Human Skin 530
  - Evolution and Human Skin 531
- 31.9** Negative Feedback in Homeostasis 532

Stem Cells—It's All About Potential (revisited) 533



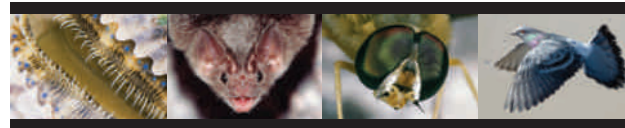
## Detailed Contents (continued)

### 32 Neural Control



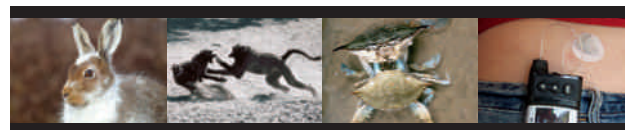
- 32.1** Impacts of Concussions 537
  - 32.2** Evolution of Nervous Systems 538
    - Nerve Net 538
    - Getting a Head 538
    - The Vertebrate Nervous System 539
  - 32.3** Neurons—The Great Communicators 540
  - 32.4** Membrane Potential 541
  - 32.5** The Action Potential 542
    - Graded Potentials and Reaching Threshold 542
    - An All-or-Nothing Spike 542
    - Propagation of an Action Potential 543
  - 32.6** How Neurons Send Messages to Other Cells 544
    - The Synapse 544
    - Cleaning the Cleft 544
    - Synaptic Integration 545
  - 32.7** Neurons' Chemical Signals 546
    - Chemically Disrupting Signaling 547
  - 32.8** The Peripheral Nervous System 548
    - Nerve Structure 548
    - Functional Divisions 548
  - 32.9** The Spinal Cord 550
    - An Information Highway 550
    - Reflex Pathways 550
    - Interrupted Spinal Signaling 550
  - 32.10** The Vertebrate Brain 552
    - Brain Development and Evolution 552
    - Ventricles and the Blood–Brain Barrier 552
    - The Human Brain 552
  - 32.11** The Human Cerebral Cortex 554
  - 32.12** Emotion and Memory 555
    - The Emotional Brain 555
    - Making Memories 555
  - 32.13** Neuroglia—The Neurons' Support Staff 556
    - Types and Functions of Neuroglia 556
    - Brain Tumors 556
- Impacts of Concussions (revisited) 557

### 33 Sensory Perception



- 33.1** Bionic Senses 561
  - 33.2** Overview of Sensory Pathways 562
    - Sensory Diversity 562
    - From Sensing to Sensation to Perception 563
  - 33.3** Somatic and Visceral Sensations 564
    - The Somatosensory Cortex 564
    - Pain 564
  - 33.4** Chemical Senses 566
    - Sense of Smell 566
    - Sense of Taste 566
    - Pheromones—Chemical Messages 567
  - 33.5** Diversity of Visual Systems 568
    - Requirements for Vision 568
  - 33.6** A Closer Look at the Human Eye 570
    - Anatomy of the Eye 570
    - Focusing Mechanisms 571
  - 33.7** Light Reception and Visual Processing 572
  - 33.8** Visual Disorders 573
  - 33.9** Vertebrate Hearing 574
    - Properties of Sound 574
    - The Vertebrate Ear 574
  - 33.10** Organs of Equilibrium 576
- Bionic Senses (revisited) 577

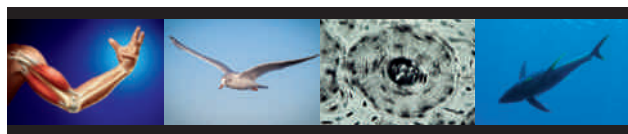
### 34 Endocrine Control



- 34.1** Hormones in the Balance 581
- 34.2** The Vertebrate Endocrine System 582
  - Mechanisms of Intercellular Signaling 582
  - Discovery of Hormones 582
  - Neuroendocrine Interactions 582

- 34.3** The Nature of Hormone Action 584  
 Categories of Hormones 584  
 Receptor Function and Diversity 584
- 34.4** The Hypothalamus and Pituitary Gland 586  
 Posterior Pituitary Function 586  
 Anterior Pituitary Function 586
- 34.5** Growth Hormone Function and Disorders 588
- 34.6** Sources and Effects of Other Vertebrate Hormones 589
- 34.7** Thyroid and Parathyroid Glands 590  
 Feedback Control of Thyroid Function 590  
 Thyroid Disorders 590  
 Thyroid Disruptors 590  
 The Parathyroid Glands 591
- 34.8** Pancreatic Hormones 592  
 Regulation of Blood Sugar 592  
 Diabetes 592
- 34.9** The Adrenal Glands 594  
 The Adrenal Cortex 594  
 The Adrenal Medulla 594  
 Stress, Elevated Cortisol, and Health 594  
 Cortisol Deficiency 595
- 34.10** The Gonads 596
- 34.11** The Pineal Gland 597
- 34.12** The Thymus 598
- 34.13** Invertebrate Hormones 598  
 Evolution of Hormone Diversity 598  
 Hormones and Molting 598
- Hormones in the Balance (revisited) 599

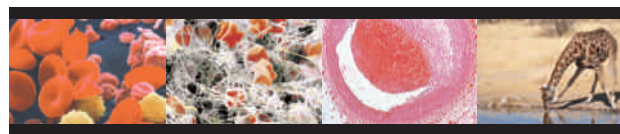
## 35 Structural Support and Movement



- 35.1** Muscles and Myostatin 603
- 35.2** Animal Movement 604
- 35.3** The Vertebrate Endoskeleton 606  
 Invertebrate Skeletons 606  
 The Vertebrate Endoskeleton 606

- 35.4** Bone Structure and Function 608  
 Bone Anatomy 608  
 Bone Formation and Remodeling 608  
 Where Bones Meet 608
- 35.5** Bone and Joint Health 610
- 35.6** Skeletal Muscle Function 611
- 35.7** How Muscle Contracts 612  
 Structure of Skeletal Muscle 612  
 The Sliding-Filament Model 612
- 35.8** Nervous Control of Muscle Contraction 614  
 Nervous Control of Contraction 614  
 Motor Units and Muscle Tension 614  
 Disrupted Control of Skeletal Muscle 615
- 35.9** Muscle Metabolism 616  
 Energy-Releasing Pathways 616  
 Types of Muscle Fibers 616  
 Effects of Exercise and Inactivity 617
- Muscles and Myostatin (revisited) 617

## 36 Circulation

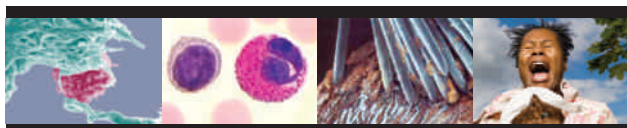


- 36.1** A Shocking Save 621
- 36.2** Circulatory Systems 622  
 Open and Closed Circulatory Systems 622  
 Evolution of Vertebrate Circulation 622
- 36.3** Human Cardiovascular System 624  
 The Pulmonary Circuit 624  
 The Systemic Circuit 624
- 36.4** The Human Heart 626  
 The Cardiac Cycle 626  
 Setting the Pace for Contraction 627
- 36.5** Vertebrate Blood 628  
 Plasma 628  
 Cellular Components 628
- 36.6** Arteries and Arterioles 630  
 Rapid Transport in Arteries 630  
 Adjusting Flow at Arterioles 630
- 36.7** Blood Pressure 631
- 36.8** Exchanges at Capillaries 632

## Detailed Contents (continued)

- 36.9** Back to the Heart **633**
  - 36.10** Blood and Cardiovascular Disorders **634**
    - Altered Blood Cell Count **634**
    - Cardiovascular Disease **634**
  - 36.11** Interactions With the Lymphatic System **636**
    - Lymphoid Vascular System **636**
    - Lymphoid Organs and Tissues **637**
- A Shocking Save (revisited) **637**

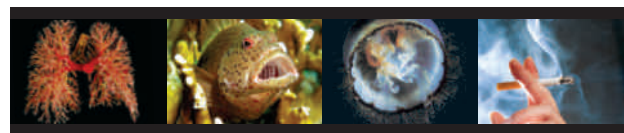
## 37 Immunity



- 37.1** Frankie's Last Wish **641**
- 37.2** Integrated Responses to Threats **642**
  - Three Lines of Defense **642**
  - The Defenders **643**
- 37.3** Surface Barriers **644**
  - Normal Flora **644**
  - Barriers to Infection **645**
- 37.4** Triggering Innate Defenses **646**
  - Complement **646**
  - Phagocytic Leukocytes **647**
- 37.5** Inflammation and Fever **648**
  - Inflammation **648**
  - Fever **649**
- 37.6** Antigen Receptors **650**
  - Antigen Receptor Diversity **651**
- 37.7** Overview of Adaptive Immunity **652**
  - Two Arms of Adaptive Immunity **652**
  - Antigen Processing **652**
- 37.8** The Antibody-Mediated Immune Response **654**
  - Antibodies and ABO Blood Typing **655**
- 37.9** The Cell-Mediated Immune Response **656**
  - Cytotoxic T Cells: Activation and Action **656**
  - The Role of Natural Killer (NK) Cells **657**
- 37.10** When Immunity Goes Wrong **658**
  - Allergies **658**
  - Overly Vigorous Responses **658**
  - Autoimmune Disorders **659**
  - Immunodeficiency **659**

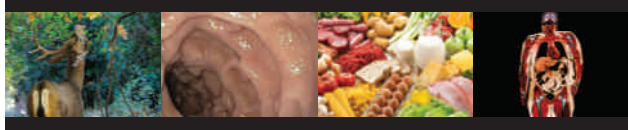
- 37.11** HIV and AIDS **660**
    - HIV Revisited **660**
  - 37.12** Vaccines **662**
    - Progress on an HIV Vaccine **663**
- Frankie's Last Wish (revisited) **663**

## 38 Respiration



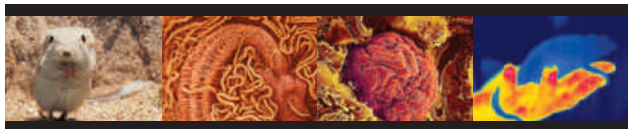
- 38.1** Carbon Monoxide—A Stealthy Poison **667**
  - 38.2** The Nature of Respiration **668**
    - Gas Exchanges **668**
    - Factors Affecting Gas Exchange **668**
    - Respiratory Medium—Air or Water? **669**
  - 38.3** Invertebrate Respiration **670**
    - Respiration in Damp or Aquatic Habitats **670**
    - Respiratory Adaptations to Life on Land **670**
  - 38.4** Vertebrate Respiration **672**
    - Respiration in Fishes **672**
    - Evolution of Paired Lungs **672**
  - 38.5** Human Respiratory System **674**
    - From Airways to Alveoli **674**
  - 38.6** How We Breathe **676**
    - The Respiratory Cycle **676**
    - Respiratory Volumes **676**
    - Control of Breathing **676**
    - Choking—A Blocked Airway **677**
  - 38.7** Gas Exchange and Transport **678**
    - The Respiratory Membrane **678**
    - Oxygen Transport **678**
    - Carbon Dioxide Transport **679**
  - 38.8** Respiratory Adaptations **680**
    - High Climbers **680**
    - Deep-Sea Divers **681**
  - 38.9** Respiratory Diseases and Disorders **682**
    - Interrupted Breathing **682**
    - Lung Diseases and Disorders **682**
    - Smoking's Impact **683**
- Carbon Monoxide—A Stealthy Poison (revisited) **683**

## 39 Digestion and Nutrition

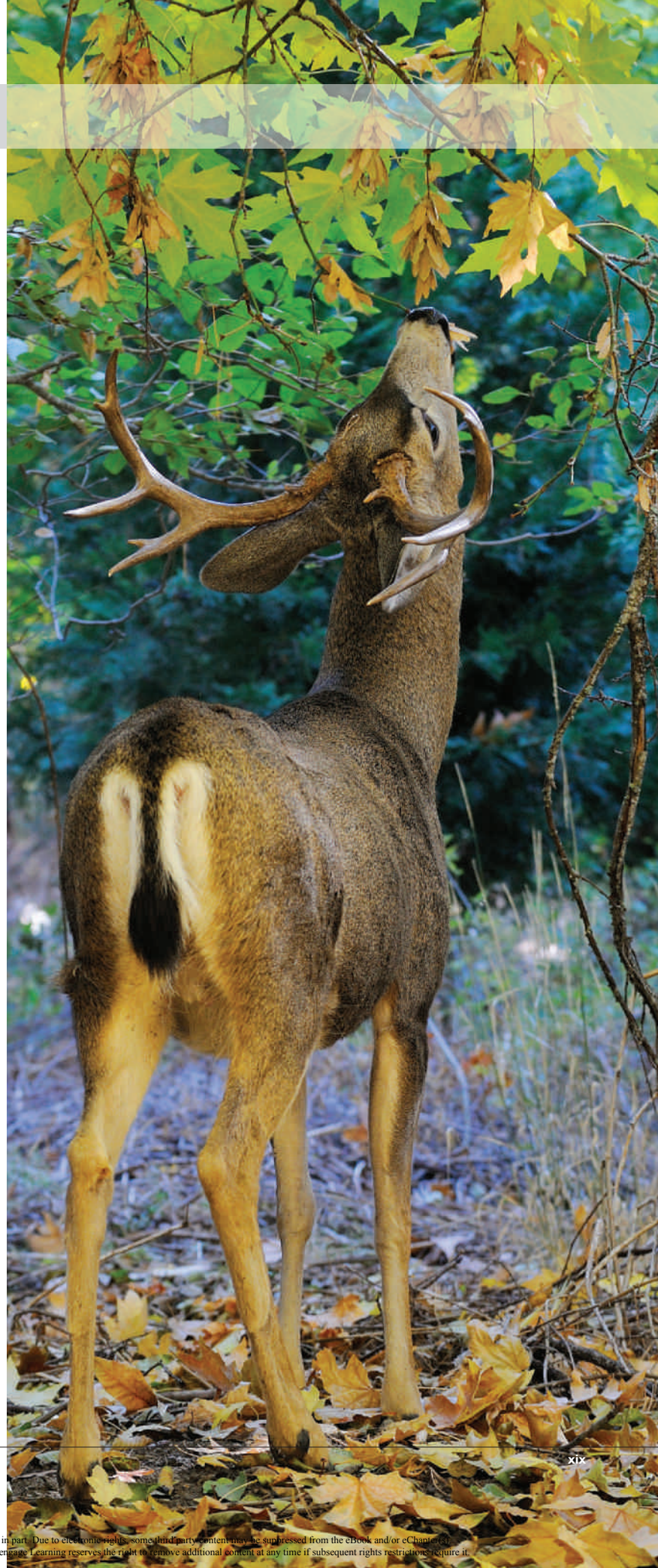


- 39.1** Your Microbial “Organ” 687
  - 39.2** Animal Digestive Systems 688
    - Food Processing Tasks 688
    - Sac or Tube? 688
  - 39.3** Overview of the Human Digestive System 690
  - 39.4** Chewing and Swallowing 691
  - 39.5** Food Storage and Digestion in the Stomach 692
  - 39.6** Structure of the Small Intestine 693
  - 39.7** Digestion and Absorption in the Small Intestine 694
    - Carbohydrate Digestion and Absorption 694
    - Protein Digestion and Absorption 694
    - Fat Digestion and Absorption 694
    - Water Absorption 695
  - 39.8** The Large Intestine 696
  - 39.9** Metabolism of Absorbed Organic Compounds 697
  - 39.10** Vitamins, Minerals, and Phytochemicals 698
  - 39.11** What Should You Eat? 700
    - Fruits, Vegetables, and Whole Grains 700
    - Heart-Healthy Oils 700
    - Lean Meat and Low-Fat Dairy 701
    - Minimal Added Salt and Sugar 701
  - 39.12** Maintaining a Healthy Weight 702
    - What Is a Healthy Weight? 702
    - Why Is Obesity Unhealthy? 702
    - Causes of Obesity 703
- Your Microbial “Organ” (revisited) 703

## 40 Maintaining the Internal Environment



- 40.1** Truth in a Test Tube 707
- 40.2** Regulating Fluid Volume and Composition 708
  - Fluid Regulation in Invertebrates 708
  - Fluid Regulation in Vertebrates 709



## Detailed Contents (continued)

- 40.3** The Human Urinary System 710
    - Organs of the Urinary System 710
    - Tubular Structure of the Kidneys 710
    - Blood Vessels of the Kidneys 711
  - 40.4** How Urine Forms 712
    - Glomerular Filtration 712
    - Tubular Reabsorption 712
    - Tubular Secretion 712
    - Concentrating the Filtrate 712
  - 40.5** Fluid Homeostasis 714
    - Fluid Volume and Tonicity 714
    - Acid–Base Balance 715
  - 40.6** When Kidneys Fail 716
    - Causes of Kidney Failure 716
    - Treating Kidney Failure 716
  - 40.7** Heat Gains and Losses 717
    - How the Core Temperature Can Change 717
    - Modes of Thermoregulation 717
  - 40.8** Adaptations to Heat or Cold 718
    - Responses to Cold 718
    - Responses to Heat 718
    - Climate-Related Adaptations in Humans 718
- Truth in a Test Tube (revisited) 719

## 41 Animal Reproductive Systems

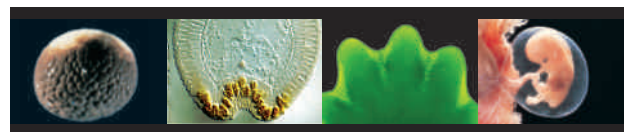


- 41.1** Assisted Reproduction 723
- 41.2** Modes of Animal Reproduction 724
  - Asexual Versus Sexual Reproduction 724
  - Variations on Sexual Reproduction 724
- 41.3** Organs of Sexual Reproduction 726
  - Gonads, Ducts, and Glands 726
  - How Gametes Form 726
- 41.4** Reproductive System of Human Females 728
  - The Female Gonads 728
  - Reproductive Ducts and Accessory Glands 728
  - Egg Production and Release 729
- 41.5** Female Reproductive Cycles 730
  - The Menstrual Cycle 730
  - The Estrous Cycle 731

- 41.6** Reproductive System of Human Males 732
  - Male Gonads 732
  - Reproductive Ducts and Accessory Glands 732
  - Germ Cells to Sperm Cells 733
- 41.7** Bringing Gametes Together 734
  - Sexual Intercourse 734
  - The Sperm's Journey 734
  - Fertilization 734
- 41.8** Contraception and Infertility 736
  - Birth Control Options 736
  - Infertility 737
- 41.9** Sexually Transmitted Diseases 738
  - Trichomoniasis 738
  - Bacterial STDs 738
  - Viral STDs 739

Assisted Reproduction (revisited) 739

## 42 Animal Development



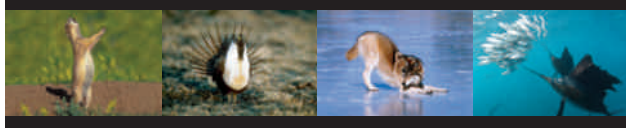
- 42.1** Prenatal Problems 743
- 42.2** Stages of Development 744
- 42.3** From Zygote to Gastrula 746
  - Components of Eggs and Sperm 746
  - Cleavage—The Start of Multicellularity 746
  - Gastrulation 747
- 42.4** How Specialized Tissues and Organs Form 748
  - Cell Differentiation 748
  - Responses to Morphogens 748
  - Embryonic Induction 748
  - Apoptosis 749
  - Cell Migrations 749
- 42.5** An Evolutionary View of Development 750
  - A General Model for Animal Development 750
  - Developmental Constraints and Modifications 750
- 42.6** Overview of Human Development 751
- 42.7** Early Human Development 752
- 42.8** Emergence of Distinctly Human Features 754
- 42.9** Structure and Function of the Placenta 756

**42.10** Labor and Childbirth 757

**42.11** Milk: Nourishment and Protection 758

Prenatal Problems (revisited) 759

## 43 Animal Behavior



**43.1** Can You Hear Me Now? 763

**43.2** Behavioral Genetics 764

Genetic Variation Within a Species 764

Genetic Variation Among Species 764

Human Behavior Genetics 765

**43.3** Instinct and Learning 766

Instinctive Behavior 766

Time-Sensitive Learning 766

Conditioned Responses 767

Other Types of Learned Behavior 767

**43.4** Environmental Effects on Behavioral Traits 768

Behavioral Plasticity 768

Epigenetic Effects 768

**43.5** Movements and Navigation 769

Taxis and Kinesis 769

Migration 769

**43.6** Communication Signals 770

Evolution of Animal Communication 770

Types of Signals 770

Eavesdroppers and

Counterfeiters 771

**43.7** Mates, Offspring, and Reproductive Success 772

Mating Systems 772

Parental Care 773

**43.8** Group Living 774

Benefits of Grouping 774

Costs of Grouping 775

**43.9** Why Sacrifice Yourself? 776

Eusocial Insects 776

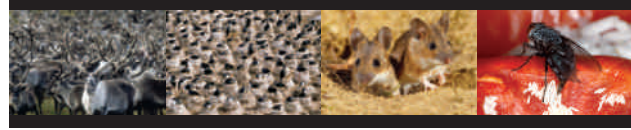
Eusocial Mole Rats 776

Evolution of Altruism 776

Can You Hear Me Now? (revisited) 777

## UNIT VII PRINCIPLES OF ECOLOGY

### 44 Population Ecology



**44.1** A Honking Mess 781

**44.2** Population Demographics 782

Population Size 782

Population Density and Distribution 782

Age Structure 783

Effects of Scale and Timing 783

**44.3** Population Size and Exponential Growth 784

Immigration and Emigration 784

Zero to Exponential Growth 784

Biotic Potential 785

**44.4** Limits on Population Growth 786

Density-Dependent Factors 786

Logistic Growth 786

Density-Independent Factors 787

**44.5** Life History Patterns 788

Quantifying Life History Traits 788

Environmental Effects on Life History 788

**44.6** Effects of Predation on Life History 790

A Long-Term Study of Guppies 790

Overfishing of Atlantic Cod 791

**44.7** Human Population Growth 792

Early Innovations and Expansions 792

From the Industrial Revolution Onward 792

**44.8** Anticipated Growth and Consumption 794

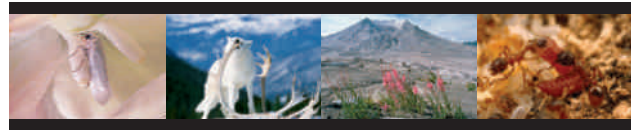
Fertility and Age Structure 794

The Demographic Transition 794

Resource Consumption 795

A Honking Mess (revisited) 796

### 45 Community Ecology



**45.1** Fighting Foreign Fire Ants 799

**45.2** What Factors Shape Community Structure? 800



## Detailed Contents (continued)

### 45.3 Mutualism 801

### 45.4 Competitive Interactions 802

- Effects of Competition 802
- Resource Partitioning 803

### 45.5 Predator–Prey Interactions 804

- Models for Predator–Prey Interactions 804
- Cyclic Changes in Abundance 804

### 45.6 Evolutionary Arms Races 806

- Coevolution of Predators and Prey 806
- Coevolution of Herbivores and Plants 807

### 45.7 Parasites and Parasitoids 808

- Parasitism 808
- Brood Parasites—Strangers in the Nest 808
- Parasitoids 809
- Biological Pest Controls 809

### 45.8 Ecological Succession 810

- Successional Change 810
- Factors That Influence Succession 810

### 45.9 Species Introduction, Loss, and Other Disturbances 812

- The Role of Keystone Species 812
- Adapting to Disturbance 812
- Species Introductions 813

### 45.10 Biogeographic Patterns in Community Structure 814

- Latitudinal Patterns 814
- Island Patterns 814

Fighting Foreign Fire Ants (revisited) 815

## 46 Ecosystems



### 46.1 Too Much of a Good Thing 819

### 46.2 The Nature of Ecosystems 820

- Overview of the Participants 820
- Trophic Structure of Ecosystems 820

### 46.3 The Nature of Food Webs 822

- How Many Transfers? 823

### 46.4 Energy Flow 824

- Primary Production 824
- Ecological Pyramids 824
- Ecological Efficiency 825

### 46.5 Biogeochemical Cycles 826

### 46.6 The Water Cycle 826

- How and Where Water Moves 826
- Limited Fresh Water 826

### 46.7 The Carbon Cycle 828

- Terrestrial Carbon Cycle 828
- Marine Carbon Cycle 829
- Carbon in Fossil Fuels 829

### 46.8 Greenhouse Gases and Climate Change 830

- The Greenhouse Effect 830
- Changing Carbon Dioxide Concentrations 830
- Changing Climate 830

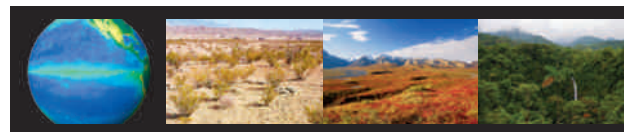
### 46.9 Nitrogen Cycle 832

- Reactions That Drive the Cycle 832
- Human Effects on the Cycle 833

### 46.10 The Phosphorus Cycle 834

Too Much of a Good Thing (revisited) 835

## 47 The Biosphere



### 47.1 Going With the Flow 839

### 47.2 Global Air Circulation Patterns 840

- Seasonal Effects 840
- Air Circulation and Rainfall 840
- Surface Wind Patterns 841

### 47.3 The Ocean, Landforms, and Climates 842

- Ocean Currents and Their Effects 842
- Regional Effects 842

### 47.4 The El Niño Southern Oscillation 844

### 47.5 Biomes 846

- Differences Between Biomes 846
- Similarities Within a Biome 846

### 47.6 Deserts 848

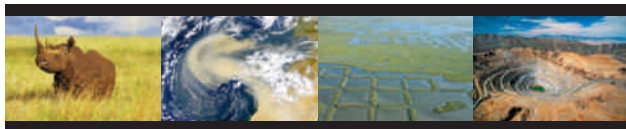
- Desert Locations and Conditions 848
- Adaptations to Desert Life 848
- The Crust Community 849

### 47.7 Grasslands 850

- Temperate Prairies 850
- Tropical Savannas 850

- 47.8** Dry Shrublands and Woodlands **851**
  - 47.9** Broadleaf Forests **852**
    - Semi-Evergreen and Deciduous Forests **852**
    - Tropical Rain Forests **852**
  - 47.10** Coniferous Forests **854**
  - 47.11** Tundra **855**
    - Arctic Tundra **855**
    - Alpine Tundra **855**
  - 47.12** Freshwater Ecosystems **856**
    - Lakes **856**
    - Streams and Rivers **857**
  - 47.13** Coastal Ecosystems **858**
    - Estuaries—Where Fresh and Saltwater Meet **858**
    - Rocky and Sandy Coastlines **859**
  - 47.14** Coral Reefs **860**
  - 47.15** The Open Ocean **862**
    - Pelagic Ecosystems **862**
    - The Seafloor **862**
- Going With the Flow (revisited) **863**

## 48 Human Impacts on the Biosphere



- 48.1** A Long Reach **867**
- 48.2** The Extinction Crisis **868**
  - Mass Extinction **868**
  - The Sixth Great Mass Extinction **869**
- 48.3** Current Diversity and Threats **870**
  - Causes of Species Declines **870**
  - The Unknown Losses **871**
- 48.4** Harmful Land Use Practices **872**
  - Desertification **872**
  - Deforestation **872**
- 48.5** Pollutants **874**
  - Acid Rain **874**
  - Biological Accumulation and Magnification **874**
  - Talking Trash **875**
- 48.6** Ozone Depletion and Pollution **876**
  - Depletion of the Ozone Layer **876**
  - Near-Ground Ozone Pollution **876**



- 48.7** Effects of Global Climate Change **877**
  - 48.8** Conservation Biology **878**
    - The Value of Biodiversity **878**
    - Setting Priorities **878**
    - Preservation and Restoration **879**
  - 48.9** Reducing Negative Impacts **880**
- A Long Reach (revisited) **881**

- Appendix I Periodic Table of the Elements
- Appendix II Amino Acids
- Appendix III Closer Look at Some Major Metabolic Pathways
- Appendix IV A Plain English Map of the Human Chromosomes
- Appendix V Restless Earth—Life's Changing Geological Stage
- Appendix VI Units of Measure
- Appendix VII Answers to Self-Quizzes and Genetics Problems

# Preface

This edition of *Biology: The Unity and Diversity of Life* includes a wealth of new information reflecting recent discoveries in biology (details can be found in the *Power Bibliography*, which lists journal articles and other references used in the revision process; available upon request). Descriptions of current research, along with photos and videos of scientists who carry it out, underscore the concept that science is an ongoing endeavor carried out by a diverse community of people. Discussions include not only what was discovered, but also how the discoveries were made, how our understanding has changed over time, and what remains to be discovered. These discussions are provided in the context of a thorough, accessible introduction to well-established concepts and principles that underpin modern biology. Every topic is examined from an evolutionary perspective, emphasizing the connections between all forms of life.

Throughout the book, text and art have been revised to help students grasp difficult concepts. This edition also continues to focus on real world applications pertaining to the field of biology, including social issues arising from new research and developments. This edition covers in detail the many ways in which human activities are continuing to alter the environment and threaten both human health and Earth's biodiversity.

## Changes to this Edition

Here are a few highlights of the revisions to this edition.

- 1 Invitation to Biology** Renewed and updated emphasis on the relevance of new species discovery and the process of science.
- 2 Life's Chemical Basis** New graphics illustrate elements and radioactive decay.
- 3 Molecules of Life** New figure illustrates protein domains.
- 4 Cell Structure and Function** New table summarizing cell theory; new photos of prokaryotes. Comparison of microscopy techniques updated using *Paramecium*. New figure shows food vacuoles in *Nassula*.
- 5 Ground Rules of Metabolism** Temperature-dependent enzyme activity now illustrated with polymerases. New art and photos illustrate coenzymes, adhesion proteins, membrane trafficking, and energy transfer in redox reactions.
- 6 Where It Starts—Photosynthesis** New photos illustrate phycobilins, stomata, adaptations of C4 plants, ice core sampling, smog in China. Light-dependent reactions art simplified.
- 7 How Cells Release Chemical Energy** New photos illustrate mitochondrial disease and aerobic respiration.
- 8 DNA Structure and Function** Concepts and illustrations of DNA hybridization and primers added to replication section. New photo of mutations caused by radiation at Chernobyl; new illustration of mutation.
- 9 From DNA to Protein** Expanded material on the effects of mutation includes discussion of hairlessness in cats and a new micrograph of a sickled blood cell.

- 10 Gene Control** New photos show transcription factors, X chromosome inactivation; new material explains evolution of lactose tolerance. New critical thinking question requires understanding of the effects of floral identity gene mutations.
- 11 How Cells Reproduce** New photos illustrate mitosis, the mitotic spindle, and telomeres.
- 12 Meiosis and Sexual Reproduction** New material on asexuality in mud snails and bdelloid rotifers. New micrograph shows multiple crossovers.
- 13 Observing Patterns in Inherited Traits** New material about environmental effects on hemoglobin gene expression in *Daphnia*. New photos illustrate continuous variation.
- 14 Chromosomes and Human Inheritance** Material on Tay-Sachs has been moved to this chapter as an illustration of autosomal recessive inheritance.
- 15 Studying and Manipulating Genomes** Coverage of personal genetic testing updated with new medical applications, including the social impact of Angelina Jolie's response to her test. New photos of genetically modified animals. New "who's the daddy" critical thinking question offers students an opportunity to analyze a paternity test based on SNPs.
- 16 Evidence of Evolution** New MRI showing coccyx illustrates a vestigial structure. Photos of 19th century naturalists added to emphasize the process of science that led to natural selection theory. Expanded coverage of fossil formation includes how banded iron formations provide evidence of the evolution of photosynthesis.
- 17 Processes of Evolution** New opening essay on resistance to antibiotics as an outcome of agricultural overuse (warfarin material moved to illustrate directional selection). New art illustrates founder effect, and hypothetical example in text replaced with reduced diversity of *ABO* alleles in Native Americans. New art illustrates stasis in coelacanth.
- 18 Organizing Information About Species** New material on DNA barcoding added to biochemical comparisons section. Data analysis activity revised to incorporate new data on honeycreeper ancestry.
- 19 Life's Origin and Early Evolution** Added material about new discovery of 3.4-billion-year old fossil bacteria. New graphic illustrates endosymbiotic origin of mitochondria and chloroplasts.
- 20 Viruses, Bacteria, and Archaea** Added information about Ebola and West Nile viruses, and newly discovered giant viruses.
- 21 Protists—The Simplest Eukaryotes** New graphic depicts primary and secondary endosymbiosis. Added information about diatoms as a source of oil.
- 22 The Land Plants** New essay about seed banks and the importance of sustain plant biodiversity.
- 23 Fungi** More extensive coverage of fungal ecology; added information about white nose syndrome, a fungal disease of bats.

**24 Animal Evolution—Invertebrates** Updated information of medicines from invertebrates. New photos of terrestrial flatworm, plant-infecting roundworm.

**25 Animal Evolution—Vertebrates** Improved discussion of transition to land, with new illustration. Reorganized coverage of mammal evolution and diversity.

**26 Human Evolution** Updated to include latest discoveries about *Australopithecus sediba*, Denisovans, and Neanderthals.

**27 Plant Tissues** Carbon sequestration essay revised to include new data on wood production by old-growth redwoods. Reorganized to consolidate primary growth into its own section. Many new photos illustrate stem, leaf, and root structure. Material on fire scars added to section on dendroclimatology.

**28 Plant Nutrition and Transport** Illustration of Casparian strip integrated with new micrograph. Revisited section discusses phytoremediation at Ford's Rouge Center.

**29 Life Cycles of Flowering Plants** Updated material reflects current research on bee pollination behavior and colony collapse. New photos illustrate pollinators, fruit classification, asexual reproduction.

**30 Communication Strategies in Plants** Updates reflect ongoing major breakthroughs in the field of plant hormone function. New photos show apical dominance, effect of gibberellin, and abscission.

**31 Animal Tissues and Organ Systems** Added information about tissue regeneration in nonhuman animals; updated information about use of human and embryonic stem cells. Added information about blubber as a specialized adipose tissue.

**32 Neural Control** New opening essay about the effects of concussion on the brain. Reorganized coverage of psychoactive drugs. Added information about epidural anesthesia. Updated, improved coverage of memory.

**33 Sensory Perception** New opening essay about cochlear implants; revisited section discusses retinal implants, artificial limbs. Updated information about human sense of taste.

**34 Endocrine Control** Updated discussion of endocrine disruptors. New examples of pituitary gigantism, dwarfism. Added information about role of melatonin in seasonal coat color changes.

**35 Structural Support and Movement** Added information about myostatin polymorphism in race horses to opening essay. New section discusses principles of animal location. Added information about boneless muscular organs such as the tongue.

**36 Circulation** More extensive coverage of plasma components. Discussion of genetics of blood types deleted. Improved coverage of and illustration of capillary exchange. Added information about blood pressure and jugular vein valves in giraffes.

**37 Immunity** Updated material on HIV/AIDS treatment strategies. New photos show T cell/APC interaction, skin as a

surface barrier, a cytotoxic T cell killing a cancer cell, contact allergy, and victims of HIV.

**38 Respiration** Improved comparison of water and air as respiratory media with accompanying figure. Revised figure depicting first aid for choking victims to reflect latest guidelines. Discussion of human adaptation to high altitude now compares mechanisms in Tibetan and Andean populations.

**39 Digestion and Nutrition** New graphic depicting functional variations in animal dentition. New figure showing arrangement of organs that empty into the small intestine. Improved discussion of vitamin and mineral functions. New MRI illustrates how abdominal fat compresses internal organs. Added information about basal metabolic rate.

**40 Maintaining the Internal Environment** New subsection about climate-related adaptations in human populations.

**41 Animal Reproductive Systems** Coverage of intersex conditions dropped. Opening essay now discusses reproductive technology (IVF, egg banking); Revisited section discusses sperm banks. New section discusses location of animal gonads and the general mechanism of gamete formation. Reproductive function of human females now discussed before that of males; improved figure depicting the ovarian cycle.

**42 Animal Development** New opening essay about human birth defects, with a focus on cleft lip and palate. Improved photos illustrating apoptosis in digit development. Reorganized coverage of early human development. Added information about surgical delivery (cesarean section).

**43 Animal Behavior** Opening essay about effects of noise pollution on animal communication moved here and updated to reflect recent research. Revised discussion of the possible benefits of grouping.

**44 Population Ecology** Improved presentation of effects of predation on guppy life history. Revised, updated graphics.

**45 Community Ecology** Added information about and a photo of a brood parasite of ants. Added photo of the keystone species *Pisaster*.

**46 Ecosystems** More extensive discussion of aquifer depletion, salination; added information about ecological effects of over-allocation of river water. Updated discussion of the rise in atmospheric CO<sub>2</sub>.

**47 The Biosphere** New opening essay about how winds and ocean currents distributed and are distributing material from the 2011 earthquake and tidal wave that affected Japan. Discussion of El Niño now a subsection within the chapter.

**48 Human Impacts on the Biosphere** New graphics of extinct animals: mastadon and dodo. Added information about and photo of endangered Florida lichen; added information about the Great Pacific Garbage Patch. Updated coverage of ozone depletion and effects of global climate change.

# Student and Instructor Resources

**Cengage Learning Testing Powered by Cognero** is a flexible, online system that allows you to:

- author, edit, and manage test bank content from multiple Cengage Learning solutions
- create multiple test versions in an instant
- deliver tests from your LMS, your classroom or wherever you want

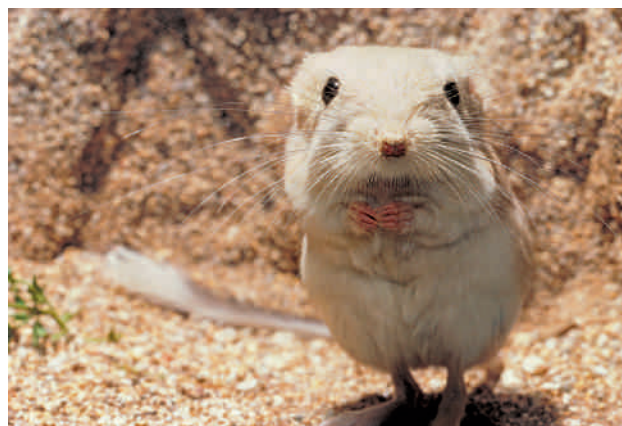
**Instructor Companion Site** Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via [www.cengage.com/login](http://www.cengage.com/login). Access and download PowerPoint presentations, images, instructor's manual, videos, and more

**Cooperative Learning** Cooperative Learning: Making Connections in General Biology, 2nd Edition, authored by Mimi Bres and Arnold Weisshaar, is a collection of separate, ready-to-use, short cooperative activities that have broad application for first year biology courses. They fit perfectly with any style of instruction, whether in large lecture halls or flipped classrooms. The activities are designed to address a range of learning objectives such as reinforcing basic concepts, making connections between various chapters and topics, data analysis and graphing, developing problem solving skills, and mastering terminology. Since each activity is designed to stand alone, this collection can be used in a variety of courses and with any text.

**MindTap** A personalized, fully online digital learning platform of authoritative content, assignments, and services that engages students with interactivity while also offering instructors their choice in the configuration of coursework and enhancement of the curriculum via web-apps known as MindApps. MindApps range from ReadSpeaker (which reads the text out loud to students), to Kaltura (allowing you to insert inline video and audio into your curriculum). MindTap is well beyond an eBook, a homework solution or digital supplement, a resource center website, a course delivery platform, or a Learning Management System. It is the first in a new category—the Personal Learning Experience.

New for this edition! MindTap has an integrated Study Guide, expanded quizzing and application activities, and an integrated Test Bank.

**Aplia for Biology** The Aplia system helps students learn key concepts via Aplia's focused assignments and active learning opportunities that include randomized, automatically graded questions, exceptional text/art integration, and immediate feedback. Aplia has a full course management system that can be used independently or in conjunction with other course management systems such as MindTap, D2L, or Blackboard.



## Acknowledgments

Writing, revising, and illustrating a biology textbook is a major undertaking for two full-time authors, but our efforts constitute only a small part of what is required to produce and distribute this one. We are truly fortunate to be part of a huge team of very talented people who are as committed as we are to creating and disseminating an exceptional science education product.

Biology is not dogma; paradigm shifts are a common outcome of the fantastic amount of research in the field. Ideas about what material should be taught and how best to present that material to students changes even from one year to the next. It is only with the ongoing input of our many academic reviewers and advisors (see opposite page) that we can continue to tailor this book to the needs of instructors and students while integrating new information and models. We continue to learn from and be inspired by these dedicated educators. A special thanks goes to Jose Panero for his extensive and detailed review for this edition.

On the production side of our team, the indispensable Grace Davidson orchestrated a continuous flow of files, photos, and illustrations while managing schedules, budgets, and whatever else happened to be on fire at the time. Grace, thank you as always for your patience and dedication. Thank you also to Cheryl DuBois, John Sarantakis, and Christine Myaskovsky for your help with photoresearch. Copyeditor Anita Hueftle and proofreader Kathy Dragolich, your valuable suggestions kept our text clear and concise.

Yolanda Cossio, thank you for continuing to support us and for encouraging our efforts to innovate and improve. Peggy Williams, we are as always grateful for your enthusiastic, thoughtful guidance, and for your many travels (and travails) on behalf of our books.

Thanks to Hal Humphrey our Cengage Production Manager, Tom Ziolkowski our Marketing Manager, Lauren Oliveira who creates our exciting technology package, Associate Content Developers Casey Lozier and Kellie Petruzzelli, and Product Assistant Victor Luu.

Lisa Starr and Christine Evers, May 2014

# Influential Class Testers and Reviewers

<b>Brenda Alston-Mills</b> North Carolina State University	<b>Amy Fenster</b> Virginia Western Community College	<b>Dr. Kevin C. McGarry</b> Kaiser College - Melbourne	<b>Robin Searles-Adenegan</b> Morgan State University
<b>Kevin Anderson</b> Arkansas State University - Beebe	<b>Kathy E. Ferrell</b> Greenville Technical College	<b>Ashley McGee</b> Alamo College	<b>Erica Sharar</b> IVC; National University
<b>Norris Armstrong</b> University of Georgia	<b>Rosa Gambier</b> Suffok Community College - Ammerman	<b>Jeanne Mitchell</b> Truman State University	<b>Julie Shepker</b> Kaiser College - Melbourne
<b>Tasneem Ashraf</b> Coshise College	<b>Tim D. Gaskin</b> Cuyahoga Community College - Metropolitan	<b>Alice J. Monroe</b> St. Petersburg College - Clearwater	<b>Rainy Shorey</b> Illinois Central College
<b>Dave Bachoon</b> Georgia College & State University	<b>Stephen J. Gould</b> Johns Hopkins University	<b>Brenda Moore</b> Truman State University	<b>Eric Sikorski</b> University of South Florida
<b>Neil R. Baker</b> The Ohio State University	<b>Laine Gurley</b> Harper College	<b>Erin L. G. Morrey</b> Georgia Perimeter College	<b>Phoebe Smith</b> Suffolk County Community College
<b>Andrew Baldwin</b> Mesa Community College	<b>Marcella Hackney</b> Baton Rouge Community College	<b>Rajkumar "Raj" Nathaniel</b> Nicholls State University	<b>Robert (Bob) Speed</b> Wallace Junior College
<b>David Bass</b> University of Central Oklahoma	<b>Gale R. Haigh</b> McNeese State University	<b>Francine Natalie Norflus</b> Clayton State University	<b>Tony Stancampiano</b> Oklahoma City Community College
<b>Lisa Lynn Boggs</b> Southwestern Oklahoma State University	<b>John Hamilton</b> Gainesville State	<b>Harold Olivey</b> Indiana University Northwest	<b>Jon R. Stoltzfus</b> Michigan State University
<b>Gail Breen</b> University of Texas at Dallas	<b>Richard Hanke</b> Rose State Community College	<b>Alexander E. Olvido</b> Virginia State University	<b>Peter Svensson</b> West Valley College
<b>Marguerite "Peggy" Brickman</b> University of Georgia	<b>Chris Haynes</b> Shelton St. Community College	<b>John C. Osterman</b> University of Nebraska, Lincoln	<b>Jeffrey L. Travis</b> University at Albany
<b>David Brooks</b> East Central College	<b>Kendra M. Hill</b> South Dakota State University	<b>Jose L. Panero</b> University of Texas	<b>Nels H. Troelstrup, Jr.</b> South Dakota State University
<b>David William Bryan</b> Cincinnati State College	<b>Juliana Guillory Hinton</b> McNeese State University	<b>Bob Patterson</b> North Carolina State University	<b>Allen Adair Tubbs</b> Troy University
<b>Lisa Bryant</b> Arkansas State University - Beebe	<b>W. Wyatt Hoback</b> University of Nebraska, Kearney	<b>Shelley Penrod</b> North Harris College	<b>Will Unsell</b> University of Central Oklahoma
<b>Katherine Buhrer</b> Tidewater Community College	<b>Kelly Hogan</b> University of North Carolina	<b>Carla Perry</b> Community College of Philadelphia	<b>Rani Vajravelu</b> University of Central Florida
<b>Uriel Buitrago-Suarez</b> Harper College	<b>Norma Hollebeke</b> Sinclair Community College	<b>Mary A. (Molly) Perry</b> Kaiser College - Corporate	<b>Jack Waber</b> West Chester University of Pennsylvania
<b>Sharon King Bullock</b> Virginia Commonwealth University	<b>Robert Hunter</b> Trident Technical College	<b>John S. Peters</b> College of Charleston	<b>Kathy Webb</b> Bucks County Community College
<b>John Capehart</b> University of Houston - Downtown	<b>John Ireland</b> Jackson Community College	<b>Carlie Phipps</b> SUNY IT	<b>Amy Stinnett White</b> Virginia Western Community College
<b>Daniel Ceccoli</b> American InterContinental University	<b>Thomas M. Justice</b> McLennan College	<b>Michael Plotkin</b> Mt. San Jacinto College	<b>Virginia White</b> Riverside Community College
<b>Tom Clark</b> Indiana University South Bend	<b>Timothy Owen Koneval</b> Laredo Community College	<b>Ron Porter</b> Penn State University	<b>Robert S. Whyte</b> California University of Pennsylvania
<b>Heather Collins</b> Greenville Technical College	<b>Sherry Krayesky</b> University of Louisiana - Lafayette	<b>Karen Raines</b> Colorado State University	<b>Kathleen Lucy Wilsenn</b> University of Northern Colorado
<b>Deborah Dardis</b> Southeastern Louisiana University	<b>Dubear Kroening</b> University of Wisconsin - Fox Valley	<b>Larry A. Reichard</b> Metropolitan Community College - Maplewood	<b>Penni Jo Wilson</b> Cleveland State Community College
<b>Cynthia Lynn Dassler</b> The Ohio State University	<b>Jerome Krueger</b> South Dakota State University	<b>Jill D. Reid</b> Virginia Commonwealth University	<b>Robert Wise</b> University of Wisconsin Oshkosh
<b>Carole Davis</b> Kellogg Community College	<b>Jim Krupa</b> University of Kentucky	<b>Robert Reinswold</b> University of Northern Colorado	<b>Michael L. Womack</b> Macon State College
<b>Lewis E. Deaton</b> University of Louisiana - Lafayette	<b>Mary Lynn LaMantia</b> Golden West College	<b>Ashley E. Rhodes</b> Kansas State University	<b>Maury Wrightson</b> Germanna Community College
<b>Jean Swaim DeSaix</b> University of North Carolina - Chapel Hill	<b>Dale Lambert</b> Tarrant County College	<b>David Rintoul</b> Kansas State University	<b>Mark L. Wygoda</b> McNeese State University
<b>(Joan) Lee Edwards</b> Greenville Technical College	<b>Kevin T. Lampe</b> Bucks County Community College	<b>Darryl Ritter</b> Northwest Florida State College	<b>Lan Xu</b> South Dakota State University
<b>Hamid M. Elhag</b> Clayton State University	<b>Susanne W. Lindgren</b> Sacramento State University	<b>Amy Wolf Rollins</b> Clayton State University	<b>Poksyn ("Grace") Yoon</b> Johnson and Wales University
<b>Patrick Enderle</b> East Carolina University	<b>Madeline Love</b> New River Community College	<b>Syधा Salihu</b> West Virginia University	<b>Muriel Zimmermann</b> Chaffey College
<b>Daniel J. Fairbanks</b> Brigham Young University		<b>Jon W. Sandridge</b> University of Nebraska	

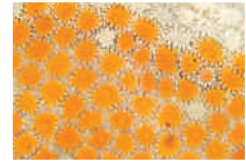
# 1 Invitation to Biology

## LEARNING ROADMAP

Whether or not you have studied biology, you already have an intuitive understanding of life on Earth because you are part of it. Every one of your experiences with the natural world—from the warmth of the sun on your skin to the love of your pet—contributes to that understanding.

### THE SCIENCE OF NATURE

We can understand life by studying it at many levels, starting with atoms that are components of all matter, and extending to interactions of organisms with their environment.



### LIFE'S UNITY

All living things require ongoing inputs of energy and raw materials; all sense and respond to change; and all have DNA that guides their functioning.



### LIFE'S DIVERSITY

Observable characteristics vary tremendously among organisms. Various classification systems help us keep track of the differences.



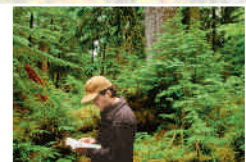
### THE NATURE OF SCIENCE

Carefully designing experiments helps researchers unravel cause-and-effect relationships in complex natural systems.



### WHAT SCIENCE IS (AND WHAT IT IS NOT)

Science addresses only testable ideas about observable events and processes. It does not address the untestable, including beliefs and opinions.



This book parallels nature's levels of organization, from atoms to the biosphere. Learning about the structure and function of atoms and molecules will prime you to understand how living cells work. Learning about processes that keep a single cell alive can help you understand how multicelled organisms survive. Knowing what it takes for organisms to survive can help you see why and how they interact with one another and their environment.

## 1.1 The Secret Life of Earth

In this era of detailed satellite imagery and cell phone global positioning systems, could there possibly be any places left on Earth that humans have not yet explored? Actually, there are plenty of them. In 2005, for example, helicopters dropped a team of scientists into the middle of a vast and otherwise inaccessible cloud forest atop New Guinea’s Foja Mountains. Within a few minutes, the explorers realized that their landing site, a dripping, moss-covered swamp, had been untouched by humans. Team member Bruce Beehler remarked, “Everywhere we looked, we saw amazing things we had never seen before. I was shouting. This trip was a once-in-a-lifetime series of shouting experiences.”

How did the explorers know they had landed in uncharted territory? For one thing, the forest was filled with plants and animals previously unknown even to native peoples that have long inhabited other parts of the region. During the next month, the team members discovered many new species, including a rhododendron plant with flowers the size of a plate and a frog the size of a pea. They also came across hundreds of species that are on the brink of extinction in other parts of the world, and some that supposedly had been extinct for decades. The animals had never learned to be afraid of humans, so they could easily be approached. A few were discovered as they casually wandered through campsites (**FIGURE 1.1**).

New species are discovered all the time, often in places much more mundane than Indonesian cloud forests. How do we know what species a particular organism belongs to? What is a species, anyway, and why

should discovering a new one matter to anyone other than a scientist? You will find the answers to such questions in this book. They are part of the scientific study of life, **biology**, which is one of many ways we humans try to make sense of the world around us.

Trying to understand the immense scope of life on Earth gives us some perspective on where we fit into it. For example, hundreds of new species are discovered every year, but about 20 species become extinct every minute in rain forests alone—and those are only the ones we know about. The current rate of extinctions is about 1,000 times faster than normal, and human activities are responsible for the acceleration. At this rate, we will never know about most of the species that are alive on Earth today. Does that matter? Biologists think so. Whether or not we are aware of it, humans are intimately connected with the world around us. Our activities are profoundly changing the entire fabric of life on Earth. These changes are, in turn, affecting us in ways we are only beginning to understand.

Ironically, the more we learn about the natural world, the more we realize we have yet to learn. But don’t take our word for it. Find out what biologists know, and what they do not, and you will have a solid foundation upon which to base your own opinions about how humans fit into this world. By reading this book, you are choosing to learn about the human connection—your connection—with all life on Earth.

---

**biology** The scientific study of life.

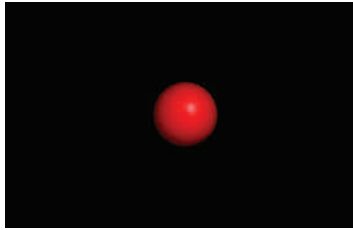


**FIGURE 1.1** Explorers found hundreds of rare species and dozens of new ones during recent survey expeditions to the Foja Mountain cloud forest (left). Right, Paul Oliver discovered this tree frog (*Litoria*) perched on a sack of rice during a particularly rainy campsite lunch. The explorers dubbed the new species “Pinocchio frog” after the Disney character because the male frog’s long nose inflates and points upward during times of excitement.



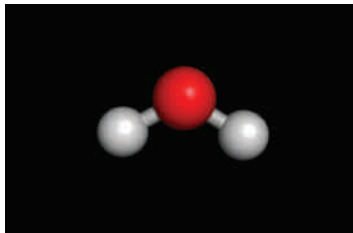
## 1.2 Life Is More Than the Sum of Its Parts

- ✓ Biologists study life by thinking about it at different levels of organization.
- ✓ The quality of life emerges at the level of the cell.



### 1 Atoms

Atoms are fundamental units of all substances, living or not. This image shows a model of a single atom.



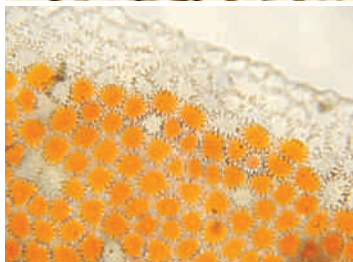
### 2 Molecule

Atoms join other atoms in molecules. This is a model of a water molecule. The molecules special to life are much larger and more complex than water.



### 3 Cell

The cell is the smallest unit of life. Some, like this plant cell, live and reproduce as part of a multicelled organism; others do so on their own.



### 4 Tissue

Organized array of cells that interact in a collective task. This is epidermal tissue on the outer surface of a flower petal.



### 5 Organ

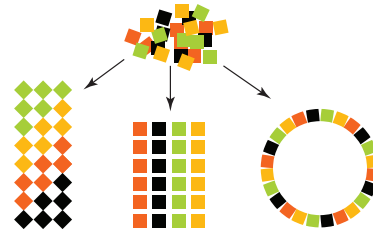
Structural unit of interacting tissues. Flowers are the reproductive organs of many plants.



### 6 Organ system

A set of interacting organs. The shoot system of this poppy plant includes its aboveground parts: leaves, flowers, and stems.

What, exactly, is the property we call “life”? We may never actually come up with a good definition, because living things are too diverse, and they consist of the same basic components as nonliving things. When we try to define life, we end up with a list of properties that differentiate living from nonliving things. These properties often emerge from the interactions of basic components. To understand how that works, take a look at these groups of squares:



The property of “roundness” emerges when the component squares are organized one way, but not other ways. Characteristics of a system that do not appear in any of the system’s components are called **emergent properties**. The idea that structures with emergent properties can be assembled from the same basic building blocks is a recurring theme in our world—and also in biology.

Life has successive levels of organization, with new emergent properties appearing at each level (FIGURE 1.2). This organization begins with interactions between **atoms**, which are fundamental building blocks of all substances 1. Atoms bond together to form **molecules** 2. There are no atoms unique to living things, but there are unique molecules. In today’s natural world, only living things make the “molecules of life,” which are lipids, proteins, DNA, RNA, and complex carbohydrates. The emergent property of “life” appears at the next level, when many molecules of life become organized as a cell 3. A **cell** is the smallest unit of life. Cells survive and reproduce themselves using energy, raw materials, and information in their DNA.

Some cells live and reproduce independently. Others do so as part of a multicelled organism. An **organism** is an individual that consists of one or more cells. A poppy plant is an example of a multicelled organism 7. In most multicelled organisms, cells are organized as tissues 4. A **tissue** consists of specific types of cells organized in a particular pattern. The arrangement allows the cells to collectively perform a special function such as protection from injury (dermal tissue) or movement (muscle tissue). An **organ** is an organized array of tissues that collectively carry out

FIGURE 1.2 ▶ Animated Levels of life’s organization.

CREDITS: (2) in text, #1, #2: © Cengage Learning; #3, #4: © Umberto Salvagnin, www.flickr.com/photos/kaibara; #5: California Poppy, © 2009, Christine M. Welter; #6: Lady Bird Johnson Wildflower Center.

a particular task or set of tasks **5**. For example, a flower is an organ of reproduction in plants; a heart, an organ that pumps blood in animals. An **organ system** is a set of organs and tissues that interact to keep the individual's body working properly **6**. Examples of organ systems include the aboveground parts of a plant (the shoot system), and the heart and blood vessels of an animal (the circulatory system).

A **population** is a group of interbreeding individuals of the same type, or species, living in a given area **8**. An example may be all California poppies living in California's Antelope Valley Poppy Reserve. At the next level, a **community** consists of all populations of all species in a given area. The Antelope Valley Reserve community includes California poppies and all other plants, animals, microorganisms, and so on **9**. Communities may be large or small, depending on the area defined.

The next level of organization is the **ecosystem**, which is a community interacting with its environment **10**. The most inclusive level, the **biosphere**, encompasses all regions of Earth's crust, waters, and atmosphere in which organisms live **11**.

**atom** Fundamental building block of all matter.

**biosphere** All regions of Earth where organisms live.

**cell** Smallest unit of life.

**community** All populations of all species in a given area.

**ecosystem** A community interacting with its environment.

**emergent property** A characteristic of a system that does not appear in any of the system's component parts.

**molecule** Two or more atoms bonded together.

**organ** In multicelled organisms, a grouping of tissues engaged in a collective task.

**organism** Individual that consists of one or more cells.

**organ system** In multicelled organisms, set of organs engaged in a collective task that keeps the body functioning properly.

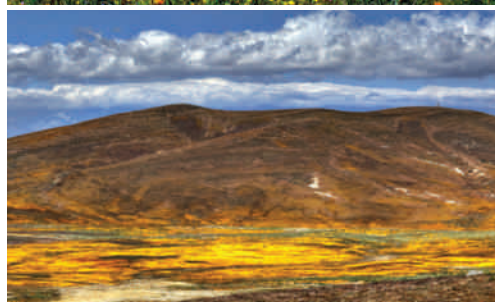
**population** Group of interbreeding individuals of the same species that live in a given area.

**tissue** In multicelled organisms, specialized cells organized in a pattern that allows them to perform a collective function.

## TAKE-HOME MESSAGE 1.2

How do living things differ from nonliving things?

- ✓ All things, living or not, consist of the same building blocks: atoms. Atoms join as molecules.
- ✓ In today's natural world, only living things make lipids, proteins, DNA, RNA, and complex carbohydrates. The unique properties of life emerge as these molecules become organized into cells.
- ✓ Higher levels of life's organization include multicelled organisms, populations, communities, ecosystems, and the biosphere.
- ✓ Emergent properties occur at each successive level of life's organization.



### 7 Multicelled organism

Individual that consists of more than one cell. Cells of this California poppy plant are part of its two organ systems: aboveground shoots and belowground roots.

### 8 Population

Group of single-celled or multicelled individuals of a species in a given area. This population of California poppy plants is in California's Antelope Valley Poppy Reserve.

### 9 Community

All populations of all species in a specified area. These plants are part of the Antelope Valley Poppy Reserve community.

### 10 Ecosystem

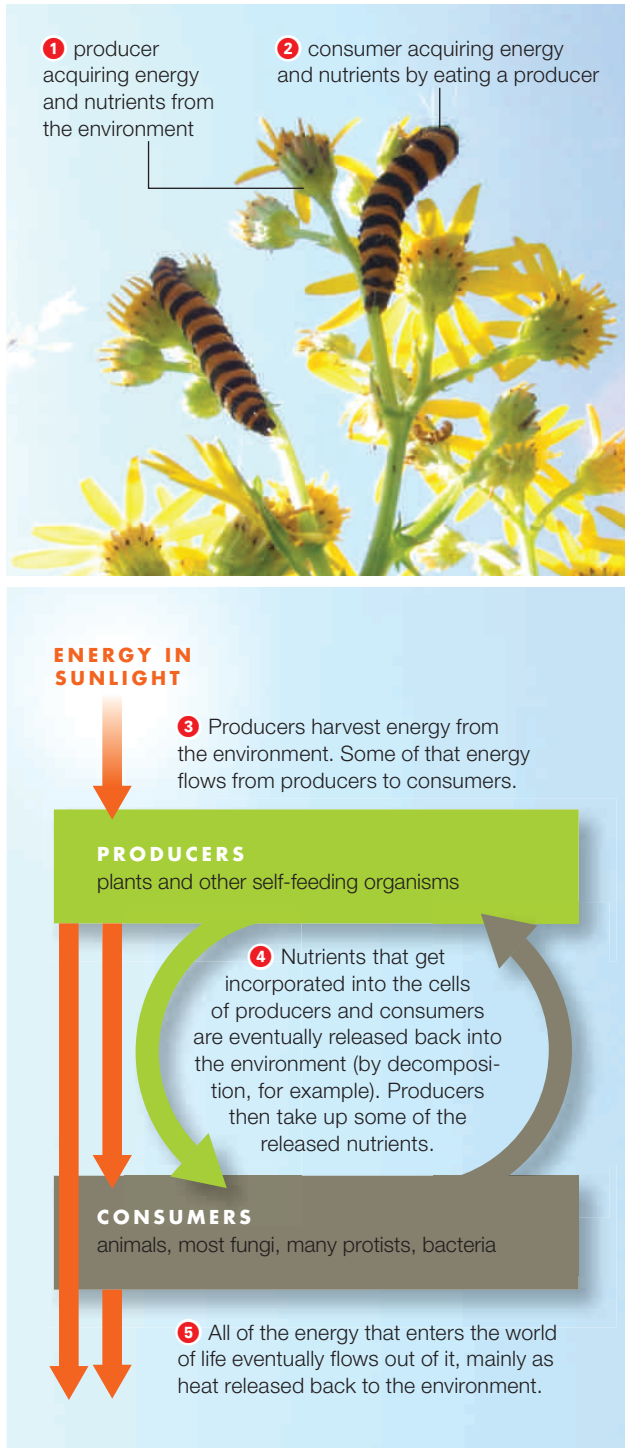
A community interacting with its physical environment through the transfer of energy and materials. Sunlight and water sustain the natural community in the Antelope Valley.

### 11 Biosphere

The sum of all ecosystems: every region of Earth's waters, crust, and atmosphere in which organisms live. No ecosystem in the biosphere is truly isolated from any other.

## 1.3 How Living Things Are Alike

- ✓ Continual inputs of energy and the cycling of materials maintain life's complex organization.
- ✓ Organisms sense and respond to change.
- ✓ All organisms use information in the DNA they inherited from their parent or parents to function.



**FIGURE 1.3 ▶ Animated** The one-way flow of energy and cycling of materials in the world of life.

Even though we cannot precisely define “life,” we can intuitively understand what it means because all living things share a set of key features. All require ongoing inputs of energy and raw materials; all sense and respond to change; and all pass DNA to offspring.

### Organisms Require Energy and Nutrients

Not all living things eat, but all require energy and nutrients on an ongoing basis. Both are essential to maintain the functioning of individual organisms and the organization of life. A **nutrient** is a substance that an organism needs for growth and survival but cannot make for itself.

Organisms spend a lot of time acquiring energy and nutrients (**FIGURE 1.3**). However, the source of energy and the type of nutrients acquired differ among organisms. These differences allow us to classify all living things into two categories: producers and consumers. **Producers** make their own food using energy and simple raw materials they obtain from nonbiological sources **1**. Plants are producers that use the energy of sunlight to make sugars from water and carbon dioxide (a gas in air), a process called **photosynthesis**. By contrast, **consumers** cannot make their own food. They obtain energy and nutrients by feeding on other organisms **2**. Animals are consumers. So are decomposers, which feed on the wastes or remains of other organisms. The leftovers from consumers’ meals end up in the environment, where they serve as nutrients for producers. Said another way, nutrients cycle between producers and consumers.

Unlike nutrients, energy is not cycled. It flows through the world of life in one direction: from the environment **3**, through organisms **4**, and back to

**consumer** Organism that gets energy and nutrients by feeding on tissues, wastes, or remains of other organisms.

**development** Multistep process by which the first cell of a new multicelled organism gives rise to an adult.

**DNA** Deoxyribonucleic acid; carries hereditary information that guides development and other activities.

**growth** In multicelled species, an increase in the number, size, and volume of cells.

**homeostasis** Process in which an organism keeps its internal conditions within tolerable ranges by sensing and responding to change.

**inheritance** Transmission of DNA to offspring.

**nutrient** Substance that an organism needs for growth and survival but cannot make for itself.

**photosynthesis** Process by which producers use light energy to make sugars from carbon dioxide and water.

**producer** Organism that makes its own food using energy and nonbiological raw materials from the environment.

**reproduction** Processes by which parents produce offspring.

**CREDITS:** (3) top, © Victoria Pinder, www.flickr.com/photos/vixstarplus; bottom, © Cengage Learning.



**FIGURE 1.4** Organisms sense and respond to stimulation. This baby orangutan is laughing in response to being tickled. Apes and humans make different sounds when being tickled, but the airflow patterns are so similar that we can say apes really do laugh.

the environment **5**. This flow maintains the organization of every living cell and body, and it also influences how individuals interact with one another and their environment. The energy flow is one-way, because with each transfer, some energy escapes as heat, and cells cannot use heat as an energy source. Thus, energy that enters the world of life eventually leaves it (we return to this topic in Chapter 5).

### Organisms Sense and Respond to Change

An organism cannot survive for very long in a changing environment unless it adapts to the changes. Thus, every living thing has the ability to sense and respond to change both inside and outside of itself (**FIGURE 1.4**). For example, after you eat, the sugars from your meal enter your bloodstream. The added sugars set in motion a series of events that causes cells throughout the body to take up sugar faster, so the sugar level in your blood quickly falls. This response keeps your blood sugar level within a certain range, which in turn helps keep your cells alive and your body functioning.

The fluid portion of your blood is a component of your internal environment, which is all of the body fluids outside of cells. That internal environment must be kept within certain ranges of temperature and other conditions, or the cells that make up your body will die. By sensing and adjusting to change, you and all other organisms keep conditions in the internal environment within a range that favors survival.

**Homeostasis** is the name for this process, and it is one of the defining features of life.

### Organisms Use DNA

With little variation, the same types of molecules perform the same basic functions in every organism. For example, information in an organism's **DNA** (deoxyribonucleic acid) guides ongoing functions that sustain the individual through its lifetime. Such functions include **development**: the process by which the first cell of a new individual gives rise to a multicelled adult; **growth**: increases in cell number, size, and volume; and **reproduction**: processes by which individuals produce offspring.

Individuals of every natural population are alike in certain aspects of their body form and behavior because their DNA is very similar: Orangutans look like orangutans and not like caterpillars because they inherited orangutan DNA, which differs from caterpillar DNA in the information it carries. **Inheritance** refers to the transmission of DNA to offspring. All organisms inherit their DNA from one or two parents.

DNA is the basis of similarities in form and function among organisms. However, the details of DNA molecules differ, and herein lies the source of life's diversity. Small variations in the details of DNA's structure give rise to differences among individuals, and also among types of organisms. As you will see in later chapters, these differences are the raw material of evolutionary processes.

### TAKE-HOME MESSAGE 1.3

How are all living things alike?

- ✓ A one-way flow of energy and a cycling of nutrients sustain life's organization.
- ✓ Organisms sense and respond to conditions inside and outside themselves. They make adjustments that keep conditions in their internal environment within a range that favors cell survival, a process called homeostasis.
- ✓ All organisms use information in the DNA they inherited from their parent or parents to develop, grow, and reproduce. DNA is the basis of similarities and differences in form and function among organisms.

## 1.4 How Living Things Differ

✓ There is great variation in the details of appearance and other observable characteristics of living things.

Living things differ tremendously in their observable characteristics. Various classification schemes help us organize what we understand about the scope of this variation, which we call Earth's **biodiversity**.

For example, organisms can be grouped on the basis of whether they have a nucleus, which is a sac with two membranes that encloses and protects a cell's DNA. **Bacteria** (singular, bacterium) and **archaea** (singular, archaeon) are organisms whose DNA is *not* contained within a nucleus. All bacteria and archaea are single-celled, which means each organism consists of one cell (**FIGURE 1.5A,B**). Collectively, these organisms are the most diverse representatives of life. Different kinds are producers or consumers in nearly all regions of Earth. Some inhabit such extreme environments as frozen desert rocks, boiling sulfurous lakes, and nuclear reactor waste. The first cells on Earth may have faced similarly hostile environments.

Traditionally, organisms without a nucleus have been called **prokaryotes**, but this designation is now used only informally. This is because, despite the similar appearance of bacteria and archaea, the two types of cells are less related to one another than we once thought. Archaea turned out to be more closely related to **eukaryotes**, which are organisms whose DNA is contained within a nucleus. Some eukaryotes live as individual cells; others are multicelled (**FIGURE 1.5C**). Eukaryotic cells are typically larger and more complex than bacteria or archaea.

Structurally, **protists** are the simplest eukaryotes, but as a group they vary dramatically, from single-celled consumers to giant, multicelled producers.

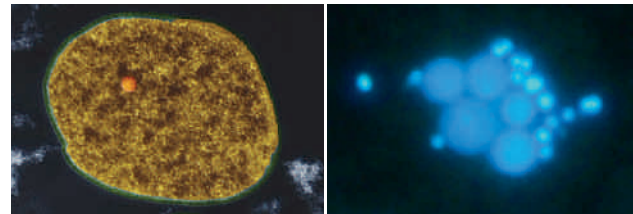
**Fungi** (singular, fungus) are eukaryotic consumers that secrete substances to break down food externally, then absorb nutrients released by this process. Many fungi are decomposers. Most fungi, including those that form mushrooms, are multicellular. Fungi that live as single cells are called yeasts.

**Plants** are multicelled eukaryotes; the majority are photosynthetic producers that live on land. Besides feeding themselves, plants also serve as food for most other land-based organisms.

**Animals** are multicelled consumers that ingest tissues or juices of other organisms. Unlike fungi, animals break down food inside their body. They also develop through a series of stages that lead to the adult form. All animals actively move about during at least part of their lives.



**A Bacteria** are the most numerous organisms on Earth. Clockwise from upper left, a bacterium with a row of iron crystals that acts like a tiny compass; a common resident of cat and dog stomachs; spiral cyanobacteria; types found in dental plaque.



**B Archaea** resemble bacteria, but are more closely related to eukaryotes. Left, an archaeon that grows in sulfur hot springs. Right, two types of archaea from a seafloor hydrothermal vent.

**FIGURE 1.5 ▶ Animated** A few representatives of life's diversity.

**animal** Multicelled consumer that develops through a series of stages and moves about during part or all of its life.

**archaea** Group of single-celled organisms that lack a nucleus but are more closely related to eukaryotes than to bacteria.

**bacteria** The most diverse and well-known group of single-celled organisms that lack a nucleus.

**biodiversity** Scope of variation among living organisms.

**eukaryote** Organism whose cells characteristically have a nucleus.

**fungus** Single-celled or multicelled eukaryotic consumer that breaks down material outside itself, then absorbs nutrients released from the breakdown.

**plant** A multicelled, typically photosynthetic producer.

**prokaryote** Single-celled organism without a nucleus.

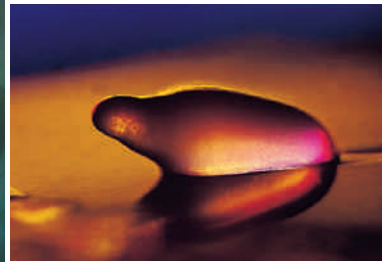
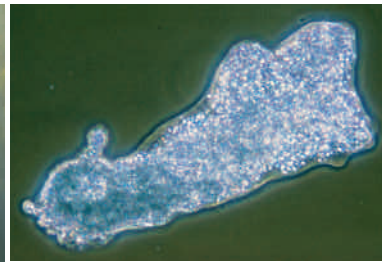
**protist** Member of a diverse group of simple eukaryotes.

### TAKE-HOME MESSAGE 1.4

How do organisms differ from one another?

- ✓ Organisms differ in their details; they show tremendous variation in observable characteristics.
- ✓ We divide Earth's biodiversity into broad groups based on traits such as having a nucleus or being multicellular.

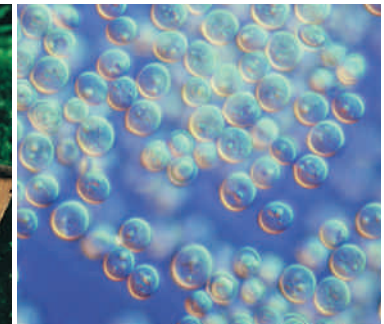
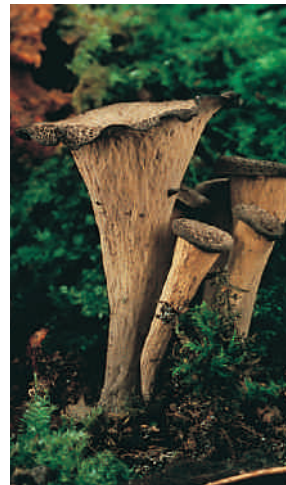
**CREDITS:** (5A) top left, Dr. Richard Frankel; top right, Science Source; bottom left, www.zahnarzt-stuttgart.com; bottom right, © Susan Barnes; (5B) left, Eye of Science/Science Source; right, © Dr. Harald Huber, Dr. Michael Hohn, Prof. Dr. K.O. Stetter, University of Regensburg, Germany.



**Protists** are a group of extremely diverse eukaryotes that range from giant multicelled seaweeds to microscopic single cells.



**Plants** are multicelled eukaryotes, most of which are photosynthetic. Nearly all have roots, stems, and leaves.



**Fungi** are eukaryotic consumers that secrete substances to break down food outside their body. Most are multicelled (left), but some are single-celled (right).



**Animals** are multicelled eukaryotes that ingest tissues or juices of other organisms. All actively move about during at least part of their life.

**C Eukaryotes** are single-celled or multicelled organisms whose DNA is contained within a nucleus.

**CREDITS:** (SC) Protists: from left, Courtesy of Allen W. H. Bé and David A. Caron; top, M I Walker/Science Source; middle, © Carolina Biological Supply Company; bottom, Oliver Meckes/Science Source; top, Courtesy of Allen W. H. Bé and David A. Caron; bottom, © Emilia Huxley photograph, Vita Pariente, scanning electron micrograph taken on a Jeol T330A instrument at Texas A&M University Electron Microscopy Center; Plants: left, © jag.ca.Shutterstock.com; right, © Martin Ruegner/Radium Images/Jupiter Images; Fungi, left, © Robert C. Simpson/Nature Stock; right, By London Scientific Films/Oxford Scientific/Getty Images; Animals, from left, © Tom & Pat Leeson, Ardea London Ltd.; Thomas Eisner, Cornell University; © Martin Zimmerman, Science, 1961, 13373-79, © AAAS; © Pixtal/SuperStock.