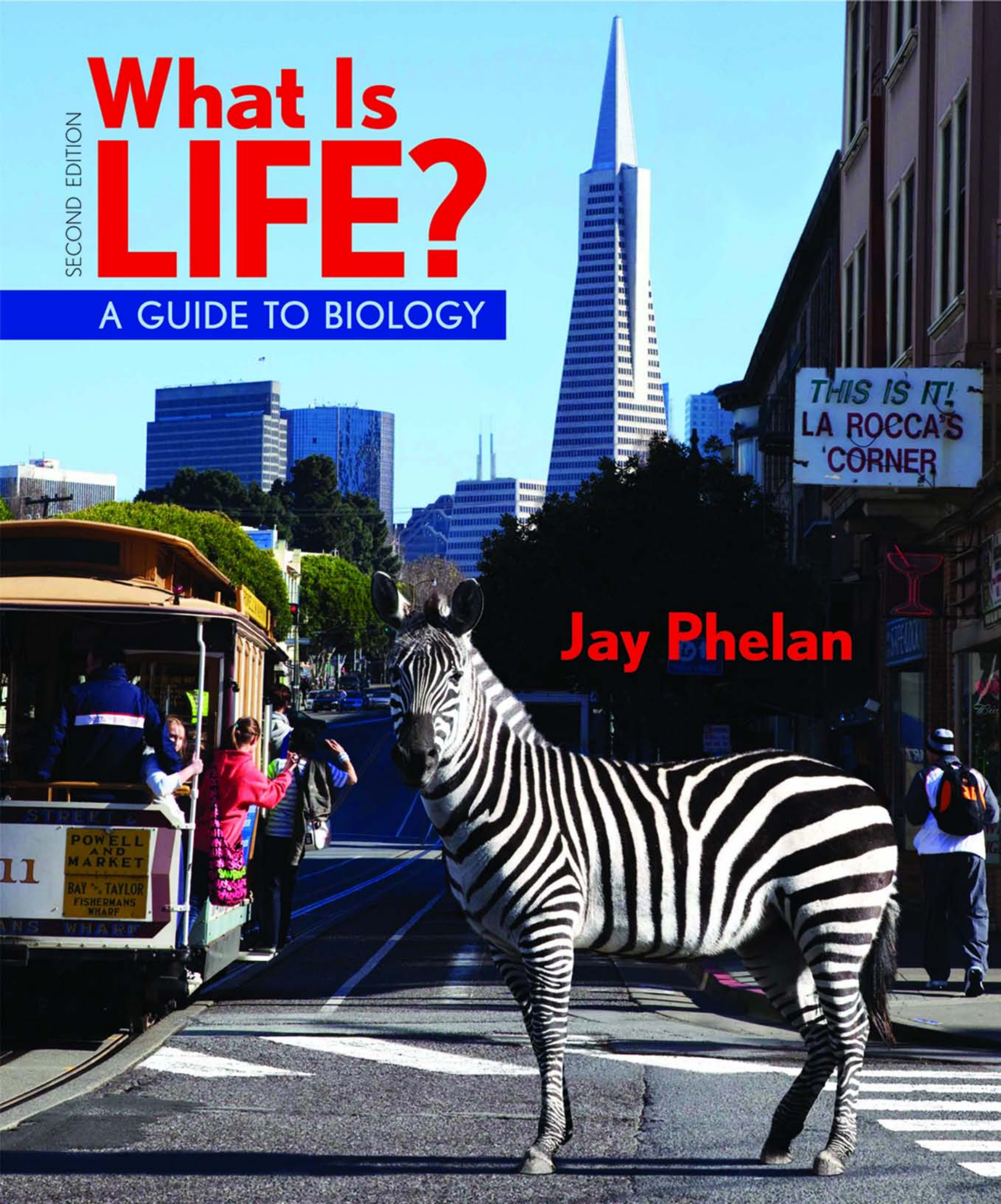


SECOND EDITION

What Is LIFE?

A GUIDE TO BIOLOGY

Jay Phelan



This page intentionally left blank

SECOND EDITION

What Is **LIFE?**

A GUIDE TO BIOLOGY

Publisher: Peter Marshall
Senior Development Editor: Elizabeth Howe
Development Editors: Jane Tufts, Alicia Moretti
Assistant Editor: Marni Rolfes
Associate Director of Marketing: Debbie Clare
Art Development Editor: Tommy Moorman
Illustrations: Tommy Moorman
Managing Editor: Philip McCaffrey
Senior Project Editor: Mary Louise Byrd
Art Director: Diana Blume
Text Design: Tom Carling, Carling Design Inc
Photo Editor: Christine Buese
Photo Researchers: Deborah Anderson, Julia Phelan
Production Manager: Susan Wein
Composition and Layout: Sheridan Sellers
Printing and Binding: Quebecor Dubuque

Library of Congress Control Number: 2011938007

Student Edition: ISBN-13: 978-1-4641-0720-7
ISBN-10: 1-4641-0720-3

Loose-leaf Edition: ISBN-13: 978-1-4641-0587-6
ISBN-10: 1-4641-0587-1

© 2013, 2010 by W. H. Freeman and Company
All rights reserved

Printed in the United States of America

First Printing

W. H. Freeman and Company
41 Madison Avenue, New York, NY 10010
Houndsmills, Basingstoke RG21 6XS, England

www.whfreeman.com

SECOND EDITION

What Is LIFE?

A GUIDE TO BIOLOGY

Jay Phelan

University of California, Los Angeles



W. H. FREEMAN AND COMPANY
NEW YORK

This page intentionally left blank

BRIEF CONTENTS

PART 1 The Facts of Life

- 1 **Scientific Thinking** | Your best pathway to understanding the world 1
- 2 **Chemistry** | Raw materials and fuel for our bodies 37
- 3 **Cells** | The smallest part of you 81
- 4 **Energy** | From the sun to you in just two steps 129

PART 2 Genetics, Evolution, and Behavior

- 5 **DNA, Gene Expression, and Biotechnology** | What is the code, and how is it harnessed? 169
- 6 **Chromosomes and Cell Division** | Continuity and variety 221
- 7 **Genes and Inheritance** | Family resemblance: how traits are inherited 263
- 8 **Evolution and Natural Selection** | Darwin's dangerous idea 299
- 9 **Evolution and Behavior** | Communication, cooperation, and conflict in the animal world 347

PART 3 Evolution and the Diversity of Life

- 10 **The Origin and Diversification of Life on Earth** | Understanding biodiversity 387
- 11 **Animal Diversification** | Visibility in motion 427
- 12 **Plant and Fungi Diversification** | Where did all the plants and fungi come from? 473
- 13 **Evolution and Diversity Among the Microbes** | Bacteria, archaea, protists, and viruses:
the unseen world 511

PART 4 Ecology and the Environment

- 14 **Population Ecology** | Planet at capacity: patterns of population growth 547
- 15 **Ecosystems and Communities** | Organisms and their environments 583
- 16 **Conservation and Biodiversity** | Human influences on the environment 623

CONTENTS

PART 1 The Facts of Life



1 • Scientific Thinking

1

Your best pathway to understanding the world

- 1-1–1-3 Science is a collection of facts and a process for understanding the world. 2**
 - 1-1 What is science? What is biology? 2
 - 1-2 Biological literacy is essential in the modern world. 4
 - 1-3 The scientific method is a powerful approach to understanding the world. 5
 - 1-4–1-10 A beginners' guide: what are the steps of the scientific method? 7**
 - 1-4 Thinking like a scientist: how do you use the scientific method? 7
 - 1-5 Step 1: Make observations. 9
 - 1-6 Step 2: Formulate a hypothesis. 9
 - 1-7 Step 3: Devise a testable prediction. 11
 - 1-8 Step 4: Conduct a critical experiment. 12
 - 1-9 Step 5: Draw conclusions, make revisions. 13
 - 1-10 When do hypotheses become theories, and what are theories? 15
 - 1-11–1-13 Well-designed experiments are essential to testing hypotheses. 16**
 - 1-11 Controlling variables makes experiments more powerful. 16
 - 1-12 Repeatable experiments increase our confidence. 19
 - 1-13 We've got to watch out for our biases. 21
 - 1-14–1-17 Scientific thinking can help us make wise decisions. 22**
 - 1-14 Visual displays of data can help us understand and explain phenomena. 22
 - 1-15 Statistics can help us in making decisions. 24
 - 1-16 Pseudoscience and misleading anecdotal evidence can obscure the truth. 26
 - 1-17 There are limits to what science can do. 28
 - 1-18 On the road to biological literacy: what are the major themes in biology? 29**
 - 1-18 A few important themes tie together the diverse topics in biology. 29
- StreetBIO: Knowledge you can use**
Rainy days and Mondays. 30



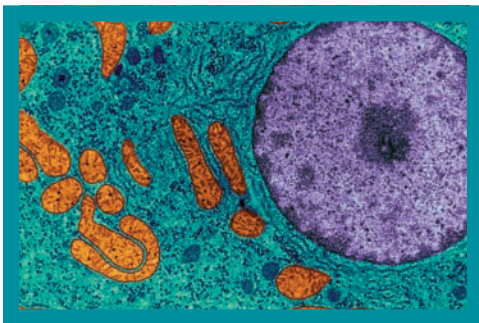
2 • Chemistry

37

Raw materials and fuel for our bodies

- 2-1–2-3 Atoms form molecules through bonding. 38**
 - 2-1 Everything is made of atoms. 38

2.2	An atom's electrons determine how (and whether) the atom will bond with other atoms.	41
2.3	Atoms can bond together to form molecules or compounds.	43
2.4–2.6	Water has features that enable it to support all life.	46
2.4	Hydrogen bonds make water cohesive.	46
2.5	Water has unusual properties that make it critical to life.	47
2.6	Living systems are highly sensitive to acidic and basic conditions.	50
2.7–2.10	Carbohydrates are fuel for living machines.	52
2.7	Carbohydrates include macromolecules that function as fuel.	52
2.8	Glucose provides energy for the body's cells.	53
2.9	Many complex carbohydrates are time-released packets of energy.	54
2.10	Not all carbohydrates are digestible.	56
2.11–2.13	Lipids store energy for a rainy day.	57
2.11	Lipids are macromolecules with several functions, including energy storage.	57
2.12	Fats are tasty molecules too plentiful in our diets.	58
2.13	Cholesterol and phospholipids are used to build sex hormones and membranes.	61
2.14–2.18	Proteins are versatile macromolecules that serve as building blocks.	63
2.14	Proteins are body-building molecules.	63
2.15	Proteins are an essential dietary component.	65
2.16	A protein's function is influenced by its three-dimensional shape.	66
2.17	Enzymes are proteins that speed up chemical reactions.	68
2.18	Enzymes regulate reactions in several ways (but malformed enzymes can cause problems).	69
2.19–2.21	Nucleic acids store information on how to build and run a body.	71
2.19	Nucleic acids are macromolecules that store information.	71
2.20	DNA holds the genetic information to build an organism.	72
2.21	RNA is a universal translator, reading DNA and directing protein production.	73
	StreetBIO: Knowledge you can use	
	Melt-in-your-mouth chocolate may not be such a sweet idea.	74



3 • Cells

The smallest part of you

81

3.1–3.3	What is a cell?	82
3.1	All organisms are made of cells.	82
3.2	Prokaryotic cells are structurally simple, but there are many types of them.	84
3.3	Eukaryotic cells have compartments with specialized functions.	86
3.4–3.7	Cell membranes are gatekeepers.	89
3.4	Every cell is bordered by a plasma membrane.	89
3.5	Molecules embedded in the plasma membrane help it perform its functions.	91
3.6	Faulty membranes can cause disease.	93
3.7	Membrane surfaces have a “fingerprint” that identifies the cell.	95
3.8–3.11	Molecules move across membranes in several ways.	97
3.8	Passive transport is the spontaneous diffusion of molecules across a membrane.	97
3.9	Osmosis is the passive diffusion of water across a membrane.	99
3.10	In active transport, cells use energy to move small molecules into and out of the cell.	101
3.11	Endocytosis and exocytosis are used for bulk transport of particles.	102
3.12	Cells are connected and communicate with each other.	105
3.12	Connections between cells hold them in place and enable them to communicate with each other.	105

3-13–3-21	Nine important landmarks distinguish eukaryotic cells.	107
3-13	The nucleus is the cell's genetic control center.	107
3-14	Cytoplasm and the cytoskeleton form the cell's internal environment, provide its physical support, and can generate movement.	109
3-15	Mitochondria are the cell's energy converters.	110
3-16	Lysosomes are the cell's garbage disposals.	112
3-17	The endoplasmic reticulum is the site where cells build proteins and disarm toxins.	114
3-18	The Golgi apparatus processes products for delivery throughout the body.	116
3-19	The cell wall provides additional protection and support for plant cells.	118
3-20	Vacuoles are multipurpose storage sacs for cells.	119
3-21	Chloroplasts are the plant cell's solar power plant.	120
	StreetBIO: Knowledge you can use	
	Drinking too much water can be dangerous!	122

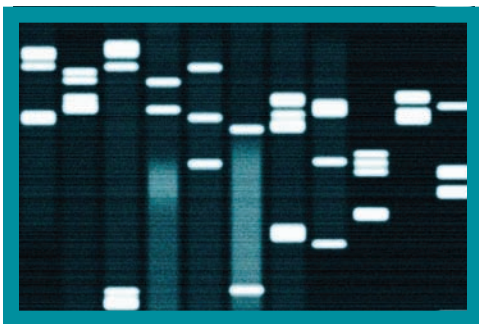


4 • Energy

129

From the sun to you in just two steps

4-1–4-4	Energy flows from the sun and through all life on earth.	130
4-1	Cars that run on french fry oil? Organisms and machines need energy to work.	130
4-2	Energy has two forms: kinetic and potential.	132
4-3	As energy is captured and converted, the amount of energy available to do work decreases.	133
4-4	ATP molecules are like free-floating rechargeable batteries in all living cells.	135
4-5–4-11	Photosynthesis uses energy from sunlight to make food.	137
4-5	Where does plant matter come from? Photosynthesis: the big picture.	137
4-6	Photosynthesis takes place in the chloroplasts.	139
4-7	Light energy travels in waves: plant pigments absorb specific wavelengths.	140
4-8	Photons cause electrons in chlorophyll to enter an excited state.	142
4-9	Photosynthesis in detail: the energy of sunlight is captured as chemical energy.	143
4-10	Photosynthesis in detail: the captured energy of sunlight is used to make food.	146
4-11	The battle against world hunger can use plants adapted to water scarcity.	147
4-12–4-15	Cellular respiration converts food molecules into ATP, a universal source of energy for living organisms.	151
4-12	How do living organisms fuel their actions? Cellular respiration: the big picture.	151
4-13	The first step of cellular respiration: glycolysis is the universal energy-releasing pathway.	152
4-14	The second step of cellular respiration: the Krebs cycle extracts energy from sugar.	154
4-15	The third step of cellular respiration: ATP is built in the electron transport chain.	156
4-16–4-17	There are alternative pathways to energy acquisition.	159
4-16	Beer, wine, and spirits are by-products of cellular metabolism in the absence of oxygen.	159
4-17	Eating a complete diet: cells can run on protein and fat as well as on glucose.	161
	StreetBIO: Knowledge you can use	
	If you feed and protect your flowers in a vase, they'll last longer.	162



5 • DNA, Gene Expression, and Biotechnology

169

What is the genetic code, and how is it harnessed?

5-1–5-5	DNA: what is it and what does it do?	170
5-1	“The DNA 200”—knowledge about DNA is increasing justice in the world.	170
5-2	DNA contains instructions for the development and functioning of all living organisms.	172
5-3	Genes are sections of DNA that contain instructions for making proteins.	174
5-4	Not all DNA contains instructions for making proteins.	176
5-5	How do genes work? An overview.	178
5-6–5-8	Building organisms: information in DNA directs the production of the molecules that make up an organism.	180
5-6	In transcription, the information coded in DNA is copied into mRNA.	180
5-7	In translation, the mRNA copy of the information from DNA is used to build functional molecules.	182
5-8	Genes are regulated in several ways.	185
5-9–5-10	Damage to the genetic code has a variety of causes and effects.	189
5-9	What causes a mutation and what are its effects?	189
5-10	Faulty genes, coding for faulty enzymes, can lead to sickness.	192
5-11–5-13	Biotechnology is producing improvements in agriculture.	194
5-11	What is biotechnology?	194
5-12	Biotechnology can improve food nutrition and make farming more efficient and eco-friendly.	198
5-13	Fears and risks: are genetically modified foods safe?	202
5-14–5-17	Biotechnology has the potential for improving human health (and criminal justice).	205
5-14	The treatment of diseases and production of medicines are improved with biotechnology.	205
5-15	Gene therapy: biotechnology can help diagnose and prevent genetic diseases, but has had limited success in curing them.	207
5-16	Cloning—ranging from genes to organs to individuals—offers both promise and perils.	209
5-17	DNA is an individual identifier: the uses and abuses of DNA fingerprinting.	211
	StreetBIO: Knowledge you can use	
	Mixing aspirin and alcohol can lead to metabolic interference and unexpected inebriation.	214



6 • Chromosomes and Cell Division

221

Continuity and variety

6-1–6-5	There are different types of cell division.	222
6-1	Immortal cells can spell trouble: cell division in sickness and in health.	222

6-2	Some chromosomes are circular, others are linear.	224
6-3	Prokaryotes divide by binary fission.	225
6-4	There is a time for everything in the eukaryotic cell cycle.	226
6-5	Cell division is preceded by replication.	227
6-6–6-9	Mitosis replaces worn-out old cells with fresh new duplicates.	229
6-6	Most cells are not immortal: mitosis generates replacements.	229
6-7	Overview: mitosis leads to duplicate cells.	231
6-8	The details: mitosis is a four-step process.	232
6-9	Cell division out of control means cancer.	234
6-10–6-14	Meiosis generates sperm and eggs and a great deal of variation.	237
6-10	Overview: sexual reproduction requires special cells made by meiosis.	237
6-11	Sperm and egg are produced by meiosis: the details, step by step.	239
6-12	Male and female gametes are produced in slightly different ways.	242
6-13	Crossing over and meiosis are important sources of variation.	244
6-14	What are the costs and benefits of sexual reproduction?	245
6-15–6-16	There are sex differences in the chromosomes.	247
6-15	How is sex determined in humans?	247
6-16	The sex of offspring is determined in a variety of ways in non-human species.	249
6-17–6-18	Deviations from the normal chromosome number lead to problems.	250
6-17	Down syndrome can be detected before birth: karyotypes reveal an individual's entire chromosome set.	250
6-18	Life is possible with too many or too few sex chromosomes.	254
	StreetBIO: Knowledge you can use	
	Can you select the sex of your baby? (Would you want to?)	256



7 • Genes and Inheritance

263

Family resemblance: how traits are inherited

7-1–7-5	Why do offspring resemble their parents?	264
7-1	Family resemblance: your mother and father each contribute to your genetic makeup.	264
7-2	Some traits are controlled by a single gene.	266
7-3	Mendel learned about heredity by conducting experiments.	268
7-4	Segregation: you've got two copies of each gene but put only one copy in each sperm or egg.	270
7-5	Observing an individual's phenotype is not sufficient for determining its genotype.	272
7-6–7-8	Probability and chance play central roles in genetics.	274
7-6	Chance is important in genetics.	274
7-7	A test-cross enables us to figure out which alleles an individual carries.	276
7-8	We use pedigrees to decipher and predict the inheritance patterns of genes.	277
7-9–7-14	The translation of genotypes into phenotypes is not a black box.	279
7-9	Incomplete dominance and codominance: the effects of both alleles in a genotype can show up in the phenotype.	279
7-10	What's your blood type? Some genes have more than two alleles.	281
7-11	Multigene traits: how are continuously varying traits such as height influenced by genes?	283
7-12	Sometimes one gene influences multiple traits.	284
7-13	Why are more men than women color-blind? Sex-linked traits differ in their patterns of expression in males and females.	285
7-14	Environmental effects: identical twins are not identical.	286

7-15–7-16	Some genes are linked together.	289
7-15	Most traits are passed on as independent features: Mendel’s law of independent assortment. 289	
7-16	Red hair and freckles: genes on the same chromosome are sometimes inherited together. 291	
	StreetBIO: Knowledge you can use	
	Can a gene nudge us toward novelty-seeking (and spicy foods)? Novelty-seeking and a gene that influences it. 292	



8 • Evolution and Natural Selection

299

Darwin’s dangerous idea

8-1	Evolution is an ongoing process.	300
8-1	We can see evolution occurring right before our eyes. 300	
8-2–8-5	Darwin journeyed to a new idea.	303
8-2	Before Darwin, many people believed that all species had been created separately and were unchanging. 303	
8-3	A job on a ‘round-the-world survey ship allowed Darwin to indulge and advance his love of nature. 305	
8-4	Observing geographic similarities and differences among fossils and living plants and animals, Darwin developed a theory of evolution. 306	
8-5	In 1859, after decades of mulling and procrastinating, Darwin published his thoughts on natural selection. 307	
8-6–8-11	Four mechanisms can give rise to evolution.	309
8-6	Evolution occurs when the allele frequencies in a population change. 309	
8-7	Mutation—a direct change in the DNA of an individual—is the ultimate source of all genetic variation. 311	
8-8	Genetic drift is a random change in allele frequencies in a population. 313	
8-9	Migration into or out of a population may change allele frequencies. 315	
8-10	When three simple conditions are satisfied, evolution by natural selection is occurring. 316	
8-11	A trait does not decrease in frequency simply because it is recessive. 320	
8-12–8-17	Through natural selection, populations of organisms can become adapted to their environments.	322
8-12	Traits causing some individuals to have more offspring than others become more prevalent in the population. 322	
8-13	Organisms in a population can become better matched to their environment through natural selection. 323	
8-14	Natural selection does not lead to perfect organisms. 324	
8-15	Artificial selection is a special case of natural selection. 325	
8-16	Natural selection can change the traits in a population in several ways. 326	
8-17	Natural selection can cause the evolution of complex traits and behaviors. 329	
8-18–8-22	The evidence for evolution is overwhelming.	331
8-18	The fossil record documents the process of natural selection. 331	
8-19	Geographic patterns of species distributions reflect their evolutionary histories. 334	
8-20	Comparative anatomy and embryology reveal common evolutionary origins. 335	
8-21	Molecular biology reveals that common genetic sequences link all life forms. 337	
8-22	Laboratory and field experiments enable us to watch evolution in progress. 338	
	StreetBIO: Knowledge you can use	
	Evolution: what it is and what it is not . . . 340	



9 • Evolution and Behavior

347

Communication, cooperation, and conflict in the animal world

9.1–9.4 Behaviors Are Traits That Can Evolve.	348
9.1 Behavior has adaptive value, just like other traits.	348
9.2 Some behaviors are innate.	350
9.3 Some behaviors must be learned (and some are learned more easily than others).	351
9.4 Complex-appearing behaviors don't require complex thought in order to evolve.	353
9.5–9.9 Cooperation, selfishness, and altruism can be better understood with an evolutionary approach.	355
9.5 "Kindness" can be explained.	355
9.6 Apparent altruism toward relatives can evolve through kin selection.	356
9.7 Apparent altruism toward unrelated individuals can evolve through reciprocal altruism.	359
9.8 In an "alien" environment, behaviors produced by natural selection may no longer be adaptive.	362
9.9 Selfish genes win out over group selection.	363
9.10–9.15 Sexual conflict can result from disparities in reproductive investment by males and females.	365
9.10 There are big differences in how much males and females must invest in reproduction.	365
9.11 Males and females are vulnerable at different stages of the reproductive exchange.	367
9.12 Tactics for getting a mate: competition and courtship can help males and females secure reproductive success.	369
9.13 Tactics for keeping a mate: mate guarding can protect a male's reproductive investment.	371
9.14 Monogamy versus polygamy: mating behaviors can vary across human and animal cultures.	373
9.15 Sexual dimorphism is an indicator of a population's mating behavior.	375
9.16–9.17 Communication and the design of signals evolve.	377
9.16 Animal communication and language abilities evolve.	377
9.17 Honest signals reduce deception.	379
StreetBIO: Knowledge you can use	
How to win friends and influence people.	380

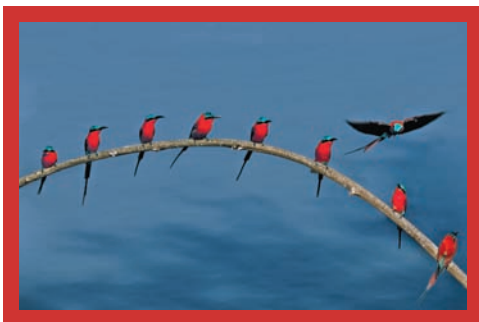


10 • The Origin and Diversification of Life on Earth

387

Understanding biodiversity

10-1–10-2	Life on earth most likely originated from non-living materials.	388
10-1	Complex organic molecules arise in non-living environments.	389
10-2	Cells and self-replicating systems evolved together to create the first life.	390
10-3–10-6	Species are the basic units of biodiversity.	392
10-3	What is a species?	392
10-4	How do we name species?	394
10-5	Species are not always easily defined.	395
10-6	How do new species arise?	397
10-7–10-9	Evolutionary trees help us conceptualize and categorize biodiversity.	401
10-7	The history of life can be imagined as a tree.	401
10-8	Evolutionary trees show ancestor-descendant relationships.	402
10-9	Similar structures don't always reveal common ancestry.	405
10-10–10-13	Macroevolution gives rise to great diversity.	407
10-10	Macroevolution is evolution above the species level.	407
10-11	The pace of evolution is not constant.	408
10-12	Adaptive radiations are times of extreme diversification.	409
10-13	There have been several mass extinctions on earth.	411
10-14–10-17	An overview of the diversity of life on earth: organisms are divided into three domains.	413
10-14	All living organisms are classified into one of three groups.	413
10-15	The bacteria domain has tremendous biological diversity.	416
10-16	The archaea domain includes many species living in extreme environments.	417
10-17	The eukarya domain consists of four kingdoms: plants, animals, fungi, and protists.	418
	StreetBIO: Knowledge you can use	
	Do racial differences exist on a genetic level?	420



11 • Animal Diversification

427

Visibility in motion

11-1–11-3	Animals are just one branch of the Eukarya domain.	428
11-1	What is an animal?	428
11-2	Four key distinctions divide the animals.	429
11-3	Everything that is not extinct is evolutionarily successful.	431

11-4	Invertebrates are animals without a backbone.....	432
11-4	Invertebrates are the largest and most diverse group of animals.	432
11-5 – 11-12	Across several evolutionary transitions, the invertebrate animals diversified. .	434
11-5	Sponges are animals that lack tissues and organs.	434
11-6	Jellyfishes and other cnidarians are among the most poisonous animals in the world.	436
11-7	Flatworms, roundworms, and segmented worms come in all shapes and sizes.	438
11-8	Most mollusks live in shells.	441
11-9	Are some animals smarter than others?	443
11-10	An external skeleton and metamorphosis produced the greatest adaptive radiation ever.	444
11-11	Other arthropods include arachnids, crustaceans, millipedes, and centipedes.	447
11-12	Echinoderms are vertebrates' closest invertebrate relatives and include sea stars, sea urchins, and sand dollars.	448
11-13 – 11-15	The phylum Chordata includes vertebrates, animals with a backbone.....	450
11-13	All vertebrates are members of the phylum Chordata.	450
11-14	The evolution of jaws and fins gave rise to the vast diversity of vertebrate species.	453
11-15	Movement onto land required lungs, a rigid backbone, four legs, and eggs that resist drying.	453
11-16 – 11-20	All terrestrial vertebrates are tetrapods.....	456
11-16	Amphibians live a double life.	456
11-17	Birds are reptiles in which feathers evolved.	457
11-18	Mammals are animals that have hair and produce milk.	459
11-19	Humans tried out different lifestyles.	461
11-20	How did we get here? The past 100,000 years of human evolution.	464
	StreetBIO: Knowledge you can use	
	Where are you from? "Recreational genomics" and the search for clues to your ancestry in your DNA.	466



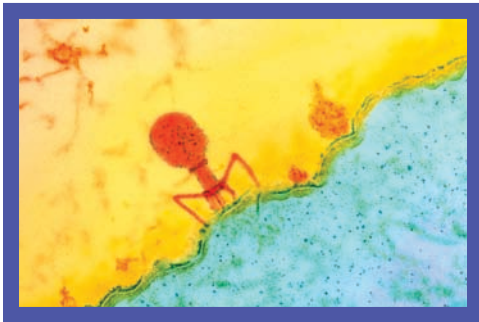
12 • Plant and Fungi Diversification

473

Where did all the plants and fungi come from?

12-1	Plants are just one branch of the eukarya.....	474
12-1	What makes you a plant?	474
12-2 – 12-4	The first plants had neither roots nor seeds.....	477
12-2	Colonizing land brings new opportunities and new challenges for plants.	477
12-3	Mosses and other non-vascular plants lack vessels for transporting nutrients and water.	478
12-4	The evolution of vascular tissue made large plants possible.	481
12-5 – 12-7	The advent of the seed opened new worlds to plants.....	483
12-5	What is a seed?	483
12-6	With the evolution of the seed, gymnosperms became the dominant plants on earth.	484
12-7	Conifers include the tallest and longest-living trees.	487
12-8 – 12-10	Flowering plants are the most diverse and successful plants.....	488
12-8	Angiosperms are the dominant plants today.	488
12-9	A flower is nothing without a pollinator.	490
12-10	Angiosperms improve seeds with double fertilization.	492
12-11 – 12-12	Plants and animals have a love-hate relationship.....	494
12-11	Fleshy fruits are bribes that flowering plants pay animals to disperse their seeds.	494
12-12	Unable to escape, plants must resist predation in other ways.	495

12-13–12-15	Fungi and plants are partners but not close relatives.	498
12-13	Fungi are closer to animals than they are to plants.	498
12-14	Fungi have common structures, but exploit an enormous diversity of habitats.	500
12-15	Most plants have fungal symbionts.	502
	StreetBIO: Knowledge you can use	
	Yams: nature's fertility food?	504



13 • Evolution and Diversity Among the Microbes

511

Bacteria, archaea, protists, and viruses:
the unseen world

13-1–13-2	There are microbes in all three domains.	512
13-1	Microbes are the simplest, but most successful organisms on earth.	512
13-2	Not all microbes are closely related evolutionarily.	514
13-3–13-5	Bacteria may be the most diverse of all organisms.	516
13-3	What are bacteria?	516
13-4	Bacterial growth and reproduction is fast and efficient.	518
13-5	Metabolic diversity among the bacteria is extreme.	519
13-6–13-9	In humans, bacteria can have harmful or beneficial health effects.	521
13-6	Many bacteria are beneficial.	521
13-7	Bacteria cause many human diseases.	522
13-8	Bacteria's resistance to drugs can evolve quickly.	523
13-9	Sexually transmitted diseases reveal battles between microbes and humans.	525
13-10–13-12	Archaea exploit some of the most extreme habitats.	526
13-10	Archaea are profoundly different from bacteria.	526
13-11	Archaea thrive in habitats too extreme for most other organisms.	527
13-12	Much archaean diversity has yet to be discovered.	528
13-13–13-15	Most protists are single-celled eukaryotes.	529
13-13	The first eukaryotes were protists.	529
13-14	There are animal-like protists, fungus-like protists, and plant-like protists.	530
13-15	Some protists can make you very sick.	532
13-16–13-19	Viruses are at the border between living and non-living.	533
13-16	Viruses are not exactly living organisms.	533
13-17	Viruses are responsible for many health problems.	535
13-18	Viruses infect a wide range of organisms.	536
13-19	HIV illustrates the difficulty of controlling infectious viruses.	538
	StreetBIO: Knowledge you can use	
	The five-second rule: how clean is that food you just dropped?	540

PART 4 Ecology and the Environment



14 • Population Ecology

547

Planet at capacity: patterns of population growth

- 14.1–14.6 Population ecology is the study of how populations interact with their environments.**..... 548
 - 14.1** What is ecology? 548
 - 14.2** A population perspective is necessary in ecology. 550
 - 14.3** Populations can grow quickly for a while, but not forever. 550
 - 14.4** A population's growth is limited by its environment. 552
 - 14.5** Some populations cycle between large and small. 554
 - 14.6** "Maximum sustainable yield" is a useful but nearly impossible-to-implement concept. 556
 - 14.7–14.9 A life history is like a species summary.**..... 559
 - 14.7** Life histories are shaped by natural selection. 559
 - 14.8** Populations can be described quantitatively in life tables and survivorship curves. 561
 - 14.9** There are trade-offs between growth, reproduction, and longevity. 563
 - 14.10–14.12 Ecology influences the evolution of aging in a population.**..... 564
 - 14.10** Things fall apart: what is aging and why does it occur? 564
 - 14.11** What determines the average longevity in different species? 567
 - 14.12** Can we slow down the process of aging? 568
 - 14.13–14.15 The human population is growing rapidly.**..... 570
 - 14.13** Age pyramids reveal much about a population. 570
 - 14.14** As less-developed countries become more developed, a demographic transition often occurs. 572
 - 14.15** Human population growth: how high can it go? 573
- StreetBIO: Knowledge you can use**
Life history trade-offs and a mini-fountain of youth: what is the relationship between reproduction and longevity? 576



15 • Ecosystems and Communities

583

Organisms and their environments

- 15.1–15.2 Ecosystems have living and non-living components.**..... 584
 - 15.1** What are ecosystems? 584
 - 15.2** A variety of biomes occur around the world, each determined by temperature and rainfall. 586
- 15.3–15.5 Interacting physical forces create weather.**..... 588
 - 15.3** Global air circulation patterns create deserts and rain forests. 588
 - 15.4** Local topography influences the weather. 590
 - 15.5** Ocean currents affect the weather. 592

15-6–15-8	Energy and chemicals flow within ecosystems.....	594
15-6	Energy flows from producers to consumers.	594
15-7	Energy pyramids reveal the inefficiency of food chains.	596
15-8	Essential chemicals cycle through ecosystems.	598
15-9–15-14	Species interactions influence the structure of communities.....	602
15-9	Interacting species evolve together.	602
15-10	Each species' role in a community is defined as its niche.	603
15-11	Competition can be hard to see, yet it influences community structure.	604
15-12	Predation produces adaptation in both predators and their prey.	605
15-13	Parasitism is a form of predation.	609
15-14	Not all species interactions are negative: mutualism and commensalism.	610
15-15–15-16	Communities can change or remain stable over time.....	612
15-15	Many communities change over time.	612
15-16	Some species are more important than others within a community.	614
	StreetBIO: Knowledge you can use	
	Life in the dead zone: in boosting plant productivity on farms, we've created a "dead zone" in the Gulf of Mexico bigger than the size of Connecticut.	616



16 • Conservation and Biodiversity

623

Human influences on the environment.

16-1–16-4	Measuring and defining biodiversity is complex.	624
16-1	Biodiversity benefits humans in many ways.	624
16-2	Biodiversity is not easily defined.	627
16-3	Where is most biodiversity?	628
16-4	Island biogeography helps us understand the maintenance and loss of biodiversity.	631
16-5–16-6	Extinction reduces biodiversity.	634
16-5	There are multiple causes of extinction.	634
16-6	We are in the midst of a mass extinction.	636
16-7–16-12	Human interference generally reduces biodiversity.	638
16-7	Some ecosystem disturbances are reversible, others are not.	638
16-8	Disruptions of ecosystems can be disastrous: 1. Introductions of exotic species.	640
16-9	Disruptions of ecosystems can be disastrous: 2. Acid rain and the burning of fossil fuels.	642
16-10	Disruptions of ecosystems can be disastrous: 3. Global climate change and the greenhouse effect.	644
16-11	Disruptions of ecosystems can be disastrous: 4. Depletion of the ozone layer.	647
16-12	Disruptions of ecosystems can be disastrous: 5. Deforestation of tropical rain forests.	649
16-13–16-14	We can develop strategies for effective conservation.	651
16-13	With limited conservation resources, we must prioritize which species should be preserved.	651
16-14	There are multiple effective strategies for preserving biodiversity.	653

StreetBIO: Knowledge you can use

The perils of (exotic) pets! 656

Periodic Table PT-1

Credits CR-1

Answers AN-1

Index I-1

Glossary GL-1

Dear Reader,

If you can learn anything from reading this book, I hope it is this: *Biology is about you, and it touches your life every day, in dozens of ways. It's creative. It's fun.*

In these pages, you'll find an overview of the key themes in biology as well as detailed information and stories about meaningful topics. I hope you will find answers to questions you're curious about, and will be spurred to ask many more, whether you are a future lawyer, teacher, entrepreneur, parent, consumer, citizen, or all of the above.

Consider these:

- Does it rain more on weekends than during the week?
- Do megadoses of vitamin C reduce cancer risk?
- Why doesn't natural selection lead to the production of perfect organisms?
- Why are big, fierce animal species so rare in the world?

As you read, you'll see big red **Qs**, identifying questions like these, often with real relevance to your own life. They point toward passages where you can uncover the answers. If you don't think the answer is found there, look again and think some more. Sometimes you know things that you don't realize you know. Sometimes, as you read, you are learning about things you're not actually reading about. Recognizing and developing these abilities will help you reason your way through novel problems and will serve you well long after you have forgotten this or that specific fact.

At the end of each chapter, you'll find a section called **StreetBIO: Knowledge You Can Use**. These sections unpack some questions and issues that are particularly practical, such as *How clean is that food you just dropped?* (see Chapter 13).

There's much more to biology than just words. Flip through *What Is Life?* and look at the **photographs**. Images can inspire and provide an alternative hook for remembering and understanding ideas. I have hand-picked every photo, with a goal of provoking, engaging, and even entertaining you, always while helping you make connections between complex ideas.

You'll also notice brief quotes from a variety of literary sources. There is a rich tradition of scientific imagery, references, and metaphors throughout literature. With these, I hope to illustrate how, as your scientific literacy is increased, so too will be the richness of your experience and appreciation of literature.

In a world of information overload, it is more important than ever to learn how to distill ideas, examples, and implications, forming hierarchies of importance. I don't want you to lose sight of the big picture. In organizing each chapter, I have broken down the topics into **discrete sections** (I think of them as nuggets). And at the end of each, I highlight the **Take-Home Message** that concisely and precisely highlights and reinforces the section's most important ideas. There is much material here, but in these short chunks you can master it. Packaged with every new copy of the book are laminated, illustrated **To-Go** summaries of each chapter.

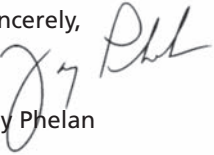
Increasingly, the information you consume includes graphs. It's essential to understand how to read and interpret such figures. To help you, I've included an exercise at the end of each chapter called **Graphic Content**. This critical thinking challenge will help you become adept at reading and analyzing visual displays of information, while identifying subtle assumptions, biases, and even manipulations.

At the end of each chapter, you'll also find review questions with a wide range of difficulties indicated by a **difficulty thermometer**. It's okay if you get some of these questions wrong. By noting the approximate

difficulty level of those giving you trouble, you'll be able to more accurately assess where you stand as you gain proficiency with the material. And there are thousands more questions available for easy and efficient practice online.

This is just a sampling of some of the features provided in this textbook. I really hope that you gain as much satisfaction from reading this book as I have received in putting it together for you.

Sincerely,

A handwritten signature in black ink, appearing to read "Jay Phelan". The signature is written in a cursive style with a large initial "J" and "P".

Jay Phelan

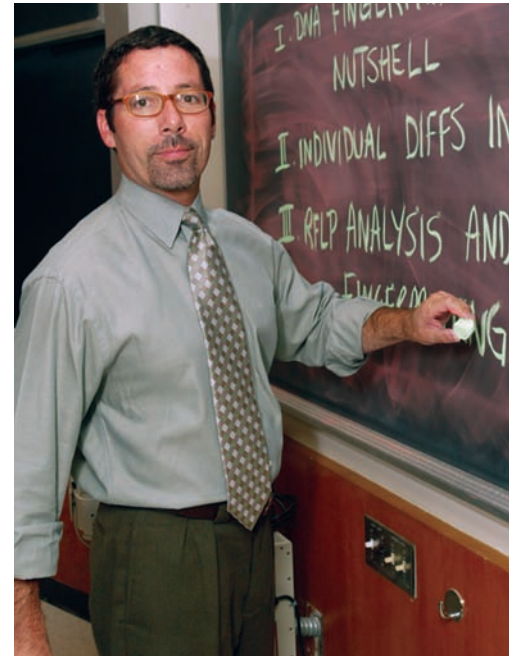
P.S. About the cover: I wanted to convey that biology isn't something that exists far away, separate from our personal lives. Rather, it intersects with our lives and is a central part of our world.

About the Author

Jay Phelan teaches biology at UCLA, where he has taught introductory biology to more than 9,000 majors and non-majors students over the past fourteen years. He is the recipient of more than a dozen teaching awards, including UCLA's highest teaching honor, the Distinguished Teaching Award, in 2011. He received his Ph.D. in evolutionary biology from Harvard in 1995, and his master's and bachelor's degrees from Yale and UCLA. His primary area of research is evolutionary genetics, and his original research has been published in *Evolution*, *Experimental Gerontology*, and the *Journal of Integrative and Comparative Biology*, among other journals. His research has been featured on *Nightline*, CNN, the BBC, and National Public Radio; in *Science Times* and *Elle*; and in more than a hundred newspapers.

Jay lectures frequently on a variety of topics in education, including the nurturing of critical thinking skills in undergraduate students, and the use and efficacy of online adaptive assessment software. His research in these areas has been published in the *International Encyclopedia of Education* and other journals.

With economist Terry Burnham, Jay is co-author of the international best-seller *Mean Genes: From Sex to Money to Food—Taming Our Primal Instincts*. Written for the general reader, *Mean Genes* explains in simple terms how knowledge of the genetic basis of human nature can empower individuals to lead more satisfying lives.



To Julia

Q HOW DOES *WHAT IS LIFE?* SO THOROUGHLY CAPTIVATE NON-MAJORS?

IT WAS CREATED WITH THEM IN MIND.

Engaging Examples

What Is Life? A Guide to Biology threads fascinating, relevant, contemporary examples throughout each chapter.

Brief Sections

Each chapter is broken down into a series of short, accessible sections.

Clear, Consistent Illustrations

Fresh and easy-to-understand figures bring the concepts to life. Collaboratively developed by the author and scientific illustrator, the text and illustrations are seamlessly integrated, effective learning tools.

Vivid Photos

Striking images appear as unit openers and are combined with illustrations of biological processes, concepts, and experimental techniques to engage the imagination of the student.



Once breeders recognized the existence of heredity, selective breeding—such as for reduced size in horses—became possible.

Intriguing, Often Surprising

Q Questions

Q questions spark students' interest and encourage critical thinking.

Q Drinking diet soda can be deadly if you carry a single bad gene. What gene is it and why is it so deadly?

THE CODON TABLE						
FIRST POSITION	SECOND POSITION			THIRD POSITION		
	U	C	A	G		
U	UUU	UCU	UAU	UGU	U	U
	UUC	UCC	UAC	UGC	C	C
	UUA	UCA	UAA	UGA	A	A
	UUG	UCG	UAG	UGG	G	G
C	CUU	CCU	CAU	CGU	C	C
	CUC	CCC	CAC	CCG	A	A
	CUA	CCA	CAA	CCG	G	G
	CUG	CCG	CAU	CCG	U	U
A	AUU	AUC	AUA	AUG	A	A
	AUA	AUU	AUU	AUU	C	C
	AUU	AUU	AUU	AUU	G	G
	AUU	AUU	AUU	AUU	U	U
G	GUU	GUC	GUA	GUG	G	G
	GUA	GUU	GUU	GUU	C	C
	GUU	GUU	GUU	GUU	A	A
	GUU	GUU	GUU	GUU	G	G

Many amino acids are specified by multiple codons. For example, GAA and GAG both specify glutamate.

Take-Home Messages

Each section of the chapter includes a concise, memorable summary of key ideas.

TAKE-HOME MESSAGE 7-11

Many traits, including continuously varying traits such as height, eye color, and skin color, are influenced by multiple genes.

End-of-Chapter Study Tools

Each chapter includes Big Ideas recaps of the key ideas from each section, Key Terms that are page-referenced for quick review, and Check Your Knowledge and short-answer questions.

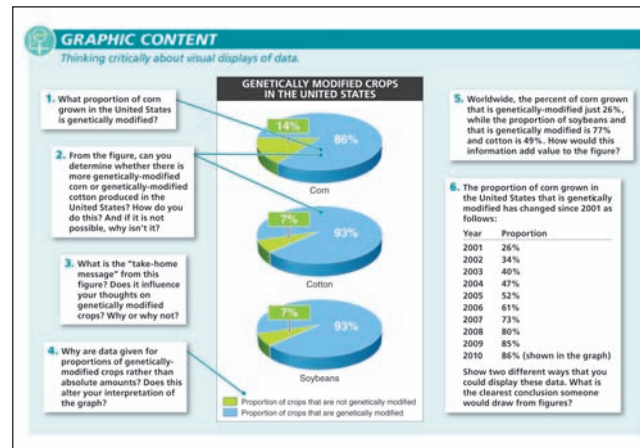
StreetBIOs

STREETBIO: KNOWLEDGE YOU CAN USE features are found at the end of every chapter, and demonstrate the practicality and fun of biology. 25 percent are new!



Graphic Content Helps Students Analyze Data and Think Critically

Each chapter features a graph or chart accompanied by a series of critical-thinking questions that requires students to evaluate the data presented.



WHAT'S THIS?

All questions are not created equal... We've determined the difficulty of these questions based on more than ten million responses from students nationwide using the online adaptive learning system Prep-U. 45% of students nationwide answered the question incorrectly.

Difficulty number is the proportion of students answering the question incorrectly. In this case, 45% of students nationwide answered the question incorrectly.

The color of the difficulty meter gives you a quick indication of the question's difficulty:

- 100 = hard
- 50 = medium
- 0 = easy

How can this help you? We've included questions with a wide range of difficulties. It's okay if you get some wrong. By noting the approximate difficulty level of those giving you trouble, you can more accurately assess where you stand as you gain proficiency with the material.

For more practice quizzes, with study questions individually selected to match your level of proficiency and to most efficiently boost it, go to www.Prep-U.com.

Prep-U
Personalized Study. Proven Results.

6. A chemical compound that releases H⁺ into a solution is called:

- a proton.
- a base.
- an acid.
- a hydroxide ion.
- a hydrogen ion.

7. Which of the following foods is not a significant source of complex carbohydrates?

- fresh fruit
- rice
- pasta
- oatmeal
- All of the above are significant sources of complex carbohydrates.

8. Sucrose (table sugar) and lactose (the sugar found in milk) are examples of:

- naturally occurring enzymes.
- simple sugars.
- monosaccharides.
- disaccharides.
- complex carbohydrates.

Prep-U Thermometers Rate the Question Difficulty

Thermometers appear next to each end-of-chapter Check Your Knowledge question to help students understand their current level of proficiency.

To-Go Guides Provide a Visual Summary of Each Chapter

These laminated guides offer a visual summary for each chapter and serve as a great study tool. They can be packaged with the text at no additional cost.

8 EVOLUTION and NATURAL SELECTION ...to go

8-11-16 Through natural selection, populations of organisms can become adapted to their environment. [Learn More](#)

When there is variation for a trait, and the variation is heritable, and there is differential reproductive success based on that trait, evolution by natural selection is occurring.

FITNESS Fitness is a measure of the relative amount of reproduction of an individual with a particular phenotype, as compared with the reproductive output of individuals with alternative phenotypes. An individual's fitness can vary, depending on the environment in which the individual lives.

In a lighter habitat, the allele for light-colored fur is favored and increases in frequency.

In a darker habitat, the allele for dark-colored fur is favored and increases in frequency.

However, adaptation does not lead to perfect organisms. For example, the average beak size in Galapagos finches fluctuates according to average rainfall and food supply.

ADAPTATION Adaptation—the process by which organisms become better matched to their environment and the specific features that make an organism more fit—occurs as a result of natural selection.

PATTERNS OF NATURAL SELECTION Natural selection can change populations in several ways.

DIRECTIONAL SELECTION The average value for a trait increases or decreases.

STABILIZING SELECTION The average value of a trait remains the same while extreme versions of the trait are selected against.

DISRUPTIVE SELECTION Individuals with extreme phenotypes have the highest fitness.

8-17-21 The evidence for the occurrence of evolution is overwhelming. [Learn More](#)

Many overwhelming lines of evidence document the occurrence of evolution and point to the central and unifying role of evolution by natural selection in helping us to better understand all other ideas and facts in biology.

THE FOSSIL RECORD Analyses of fossil remains enables biologists to reconstruct what organisms looked like long ago, learn how organisms were related to each other, and understand how groups of organisms evolved over time.

COMPARATIVE ANATOMY and EMBRYOLOGY Similarities in the anatomy of different groups of organisms and in their physical appearance as they proceed through their development can reveal common evolutionary origins.

COMMON GENETIC SEQUENCES All living organisms share the same genetic code. The degree of similarity in the DNA of different species can reveal how closely related they are and the amount of time that has passed since they last shared a common ancestor.

BIOGEOGRAPHY Drawing geographic patterns of species distributions helps us to understand the evolutionary histories of populations. For example, Hawaiian honeycreepers have adapted to a wide range of habitats, yet still closely resemble a finch-like shared ancestor found nearly 2,000 miles away.

Embryology: Chick embryo, Human embryo, Chicken embryo.

Common Genetic Sequences: Human, Rhesus monkey, Dog, Bird, Lamprey.

Acknowledgments

As a new graduate student at Harvard, I heard from experienced teaching fellows that if you were interested in learning how to be an effective teacher, it was essential to seek out extraordinary mentors. Based on word of mouth, I became involved with E. O. Wilson's course in Evolutionary Biology and Irven DeVore's course in Human Behavioral Biology. Both were known to be unusually provocative, challenging, and entertaining classes for non-science majors. I aggressively pursued teaching positions in both classes—which I held onto tightly for twelve semesters. Working under these legendary instructors, I was set on a course that inspired and prepared me to write this book.

The two courses were quite different from each other, but at their core both were built on two beliefs that are central to this book and to my thinking about education: (1) Biology is creative, interesting, and fun. (2) Biology is relevant to the daily life of every person. There was a palpable sense that, in teaching non-science majors especially, we had a responsibility to provide our students with the tools to thrive in a society increasingly permeated by scientific ideas and issues, and that one of our most effective strategies would be to convey the excitement we felt for biology and the enormous practical value it has to help us understand the world. I thank Professors Wilson and DeVore for all that they have shared with me.

My development as a scientist and, particularly, my appreciation for rigorous and methodical critical thinking have been shaped by the kind support and wise guidance of Richard Lewontin. I have also been fortunate to have as a long-time mentor and collaborator Michael Rose, who has instilled in me a healthy skepticism about any observation in life that is not fivefold replicated. And for almost daily insightful input on matters relating to scientific content, teaching, writing, and more, I thank Terry Burnham.

There are many other friends and colleagues I wish to thank for helping me with *What Is Life?*

In researching and writing the book and in developing the numerous courses I teach, I have benefited from more than a decade of perceptive and valuable contributions, too numerous to list, from Glenn Adelson, Alon Ziv, Michael Cooperson, and Alicia Moretti. I am tremendously appreciative of all they have done for me.

For a project covering so many topics and years, it is essential to have a close group of trusted, tolerant, and knowledgeable colleagues, I am grateful to Harold Owens, Greg Graffin, Brian

Swartz, Greg Laden, Jeff Egger, Andy Tobias, Elisabeth Tobias, Joshua Malina, Melissa Merwin-Malina, Bill U'ren, Chris Bruno, Michelle Richmond, and Meredith Dutton, who have offered advice, guidance, and support, far beyond the call of duty.

Numerous colleagues at UCLA provided assistance and support, including Steve Strand, Cliff Brunk, Fred Eiserling, Emil Reisler, Victoria Sork, Deb Pires, Lianna Johnson, Gaston Pfluegl, Bob Simons, Frank Laski, Jeff Thomas, and Tracy Newman. As a result of their commitment to excellence in the UCLA Life Science Core Curriculum, I have been able to acquire a wealth of experiences that have helped me continue improving as a teacher.

I owe a tremendous debt to Sara Tenney, without whose encouragement and support this project could never have been begun or completed.

W. H. Freeman is an extremely author-centric publisher. Throughout the process of creating this book, from the first inception of the idea through the production of all the supplementary materials, Liz Widdicombe, Brian Napack, and John Sargent have been tremendously supportive. I am grateful for their welcoming me into their publishing family. Publisher Peter Marshall has been a tenacious, versatile, and skillful manager of the entire team. I am very fortunate to have such a wise leader overseeing all aspects of this project.

The team of editors that worked with me on this book—and two people in particular—improved it immeasurably. Development editor Beth Howe, oversaw every aspect of the writing and production of the book, attending to issues of content, production, and design while making insightful contributions throughout and expertly managing the thousand details necessary to put everything together. I could not have completed this book without Beth's commitment and guidance. And I cannot adequately convey my gratitude to development editor Jane Tufts, whose meticulous attention to detail, commitment to accuracy, and almost obsessive drive to create a thorough and readable book are apparent on every page.

It is impossible to teach biology without illustrations. My deepest gratitude goes to Tommy Moorman for creating such innovative and effective figures for the book. Tommy's vision for an elegant and beautiful art program completely integrated with the text is apparent on every page. Working with him to develop each illustration in this book has been (and continues to be) one of my most enjoyable and satisfying professional collaborations. Thanks also go to Alison Kendall and to Erin Daniel for assisting with the creation of the illustrations and

for work on the To Go guides. For the design of the book, I thank Tom Carling. And for excellent assistance with photo research thanks to Julia Phelan, Deborah Anderson, and Christine Buese.

I wish to thank Harvey Pough for his assistance with the first edition of *What Is Life?* for which he provided excellent drafts of Chapters 11–13 and contributions to Chapter 16.

For creating the innovative media and print materials that accompany the book, I am thankful for the contributions of Patrick Shriner, Mike Jones, and Beth McHenry, and for the extensive input of supplements editors Amanda Dunning and Marni Rolfes. I thank all of the contributors and advisors who helped create the student and instructor resources; your efforts have been invaluable. I thank Jennifer Warner and Meredith Norris for their work on the Student Success Guide, and for Jennifer’s willingness to share her classroom experiences with the sales force. I also appreciate the contributions of Troy Williams and the Prep-U team. Sheri Snavelly provided significant input in developing pedagogical strategies throughout the book; I also appreciate her thoughtful and smart advice at nearly every step in the publishing process.

Copyeditor Linda Strange helped to ensure consistency and readability throughout the text. I thank Chris Hunt for compiling the thorough index. The rest of the life sciences editorial team at W. H. Freeman, too, have been knowledgeable and supportive, particularly Kate Parker, Marc Mazzoni, Jerry Correa, Susan Winslow, Elaine Palucki, and Lisa Samols.

For their efficiency and commitment to producing a beautiful book, I am most grateful to the W. H. Freeman production team: Sheridan Sellers, Mary Louise Byrd, Diana Blume, Susan Wein, Philip McCaffrey, and Ellen Cash.

The people on the marketing team at W. H. Freeman have contributed enormously in helping with the challenging task of introducing a new book to students and instructors across the country. Debbie Clare, Steve Rigolosi, Lindsey Veautour, and John Britch have been enthusiastic and dedicated in creating materials and strategies to assist instructors in evaluating the ways in which *What Is Life?* can aid them as they develop their own courses and strategies for success.

Finally, I thank my family—Kevin Phelan, Patrick Phelan, Erin Enderlin, and my parents—for their unwavering support and interest as I wrote this book. Reading draft after draft and following each revision, they made valuable contributions at every stage. I thank Jack, Charlie, and Sam, too. Most of all, for her generous and passionate support of this project from day one, her substantive contributions to both the content and presentation of ideas, and so much more, I thank Julia.

Contact the author with your feedback.

The content of this book has been greatly improved through the comments of reviewers and students. Your comments, suggestions, and criticism are also welcome; they are essential in guiding its ongoing evolution. Please contact the author at jay@jayphelan.com. I’m serious.

We thank the many reviewers that aided in the development of this text.

Second Edition Text Development

Jessica Adams, Southwestern Illinois College
Sylvester Allred, Northern Arizona University
Nina Baghai-Riding, Delta State University
E. A. Bailey, Alamance Community College
Donna Becker, Northern Michigan University
Donna Bivans, Pitt Community College
TJ Bliss, Brigham Young University
Barbara Blonder, Flagler College
Judy Bluemer, Morton College
Lisa Boggs, Southwestern Oklahoma State University
Bruno Borsari, Winona State University
Laura Bradshaw, Illinois Central College
Judy Brooks, Blinn College
Wendy Brown, Danville Area Community College
Bruce Carroll, Lone Star College–North Harris
Michelle Cawthorn, Georgia Southern University
Jianguo Chen, Claflin University
Richard Cheney, Christopher Newport University
Genevieve Chung, Broward College
Elizabeth Co, Diablo Valley College
Robert Conover, Glendale College
Erica Corbett, Southeastern Oklahoma State University
Cathy Cornett, University of Wisconsin–Platteville
Sarah Cotton, Chaffey College
James Courtright, Marquette University
Richard Cowart, University of Dubuque
Hattie Dambroski, Normandale Community College
Jim Daugherty, Glendale Community College
Buffany DeBoer, Wayne State College
Jennifer Dechaine, Central Washington University
Tracy Deem, Bridgewater College
Craig Denesha, Spartanburg Community College
Hartmut Doebel, George Washington University
Brett Dooley, Patrick Henry Community College
Hawkins Dowis, Fresno City College
Dani DuCharme, Waubonsee Community College
Jacquelyn Duke, Baylor University
Susan Epperson, University of Colorado, Colorado Springs
Marirose Ethington, Genesee Community College
Arnaldo Ferreira, Chaffey College
Ryan Fisher, Salem State University
Reza Forough, Bellevue College
Brandon Foster, Wake Technical Community College
Cynthia Galloway, Texas A&M University–Kingsville
Joseph Gar, West Kentucky Community and Technical College
Alexandros Georgakilas, East Carolina University

Patricia Geppert, University of Texas at San Antonio
Julie Gibbs, College of DuPage
Caitlin Gille, Pasco Hernando Community College
Becky Graham, Ohio Dominican University
Sherri Graves, Sacramento City College
Jeff Green, Nashville State Community College
Cindy Gustafson-Brown, University of California, San Diego
Sue Habeck, Tacoma Community College
Mark Haefele, Community College of Denver
Thomas Horvath, State University of New York–Oneonta
Anne-Marie Hoskinson, Gustavus Adolphus College
Laurie Host, Harford Community College
Catherine Hurlbut, Florida State College at Jacksonville
Godwin Ifere, Clark Atlanta University
Virginia Irintcheva, Black Hawk College
Robert Iwan, Inver Hills Community College
Mark Jackson, Central Connecticut State University
Elisabeth Javazon, Morehouse College
John Jenkin, Blinn College
Mitrick Johns, Northern Illinois University
Scott Johnson, Wake Technical Community College
Richard Karp, University of Cincinnati
Elena Keeling, California Polytechnic State University
Joe Keen, Patrick Henry Community College
Amanda Kin, Jefferson State Community College
Melissa Kosinski-Collins, Brandeis University
Joe Kremer, Alvernia University
Dana Kurpius, Elgin Community College
Karen Kurvink, Moravian College
Kim Lackey, University of Alabama
Jordana LaFantasie, Fort Hays State University
Ellen Lamb, University of North Carolina at Greensboro
Lorraine Leiser, Southeast Community College
Laurie Len, El Camino College
Suzanne Long, Monroe Community College
Mark Manteuffel, St. Louis Community College
Brian Maricle, Fort Hays State University
John Markham, University of Manitoba
Jennifer Maupin, Santa Barbara City College
Maura McGrail, Iowa State University
Michael McLeod, Belmont Abbey College
Patricia Melloy, Fairleigh Dickinson University
Diane Melroy, University of North Carolina at Wilmington
Rachel Mintell, Manchester Community College
June Minter, Patrick Henry Community College
Kiran Misra, Edinboro University of Pennsylvania
Alice Monroe, St. Petersburg College
Frances Moore, Patrick Henry Community College

Ulrike Muller, California State University–Fresno
Necia Nicholas, Calhoun Community College
Zia Nisani, Antelope Valley College
Fran Norflus, Clayton State University
Chuma Okere, Clark Atlanta University
Marie Panec, Moorpark College
Wilene Pangle, The Ohio State University
Randi Papke, Southwestern Illinois College
Micah Perkins, Owensboro Community and Technical College
Lori Pitkofsky, Ramapo College of New Jersey
Anita Plagge, San Diego Mesa College
Michael Plotkin, Mt. San Jacinto College
Heather Prestridge, Blinn College
Stuart Reichler, University of Texas at Austin
Sheila Reilly, Belmont Abbey College
Carol Rhodes, Canada College
Bill Rogers, Ball State University
John Rousseau, Whatcom Community College
Matthew Rowe, Sam Houston State University
Edward Saiff, Ramapo College of New Jersey
Eduardo Salazar, Temple College
John Schampel, Phoenix College
Roger Seeber, West Liberty University
Brian Seymour, Edward Waters College
Dave Sheldon, St. Clair County Community College
Cara Shillington, Eastern Michigan University
Jack Shurley, Idaho State University
Dale Smoak, Piedmont Technical College
Suzanne Sousa, Middlesex Community College
Agnes Southgate, College of Charleston
Richard Stiehl, Pima Community College
Lisa Strain, Northeast Lakeview College
Jackie Swanik, Wake Technical Community College
Robert Swatski, Harrisburg Area Community College–York Campus
Ignatius Tan, New York University
John Taylor, Southern Utah University
Pamela Thinesen, Century College
Douglas Thrower, University of California, Santa Barbara
Nina Thumser, Edinboro University of Pennsylvania
Elizabeth Tomlin, University of North Carolina at Greensboro
Edward Tucker, Baruch College, City University of New York
Virginia Turner, Harper College
Kimberly Vietti, Illinois Central College
Thomas Vogel, Western Illinois University
Joanna Vondrasek, Piedmont Virginia Community College
Dennis Walsh, MassBay Community College
Yunqiu Wang, University of Miami
Katherine Warpeha, University of Illinois at Chicago
David Webb, St. Clair County Community College
Michael Wenzel, California State University–Sacramento
Tina Whitney, Governors State University
Robert Whyte, California University of Pennsylvania

Rachel Wiechman, West Liberty University
Donald Wood, Odessa College
Dulce Zayas-Alvarez, Southwestern Community College
David Zeigler, University of North Carolina at Pembroke
Jacquelyn Zevenbergen, Kent State University, Stark Campus
Brenda Zink, Northeastern Junior College
Gerald Zuercher, University of Dubuque

Second Edition Focus Group Participants

(2010, Albuquerque)

Tonya Bates, University of North Carolina at Charlotte
Craig Clifford, Northeastern State University, Oklahoma
Danielle DuCharme, Waubensee Community College
Ana Escandon, Los Angeles Harbor College
Mark Hens, University of North Carolina at Greensboro
Jessica Hopkins, University of Akron
Lorraine Leiser, Southeast Community College
Ashley Ramer, University of Akron
Sydha Salihu, West Virginia University
Jennifer Stueckle, West Virginia University
Jennifer Warner, University of North Carolina at Charlotte

(2010, New York City)

Joseph Ahlander, Northeastern State University
Tami Asplin, North Dakota State University
Caroline “Lena” Ballard, Rock Valley College
Charlotte Borgeson, University of Nevada–Reno
Susan Bower, Pasadena College
Greg Dalhem, North Kentucky University
Moon Draper, University of Texas at Austin
Gloria Hoffman, Morgan State University
Craig Jordan, University of Texas at San Antonio
Michael Koban, Morgan State University
Josephine Kurdziel, University of Michigan
Ellen Lamb, University of North Carolina at Greensboro
Jennifer Scoby, Illinois Central College

(2011, New York City)

Jennie Bever, Arizona State University
Michelle Cawthorn, Georgia Southern University
John Constable, California State University–Fresno
Elisabeth Javazon, Morehouse College
Brian Kram, Prince George’s Community College
Lorraine Leiser, Southeast Community College
Cassandra Moore-Crawford, Prince George’s Community College
Ulrike Müller, California State University–Fresno
Wilene Pangle, The Ohio State University
Jennifer Warner, University of North Carolina at Charlotte
Michael Wenzel, California State University–Sacramento
and Folsom Lake Community College

First Edition Text Development

Stephanie J. Aamodt, University of Louisiana—Shreveport
M. Stephen Ailstock, Anne Arundel Community College
Sylvester Allred, Northern Arizona University
Jessica K. Baack, Montgomery Community College—
Rockville
Sarah Barlow, Middle Tennessee State University
Rebecca A. Bartow, Western Kentucky University
Brian J. Baumgartner, Trinity Valley Community College
Jose Bava, El Camino Community College
Lisa L. Boggs, Southwestern Oklahoma State University
Charlotte Borgeson, University of Nevada—Reno
Peggy Brickman, University of Georgia
Jason Brown, Young Harris College
Carole L. Browne, Wake Forest University
Neil J. Buckley, State University of New York—Plattsburgh
Anne E. Bunnell, East Carolina University
Joseph Burdo, Bridgewater State University
David Byres, Florida Community College at Jacksonville
William Caire, University of Central Oklahoma
Michael S. Carr, Oakton Community College
Kelly Carrillo Burke, College of the Canyons
Thomas Chen, Santa Monica College
Thomas F. Chubb, Villanova University
Nira Clark, Southwestern College
Erica Cline, University of Washington
George Clokey, University of Wisconsin—Whitewater
Anthony D. Cornett, Valencia Community College, Osceola
Karen Curto, University of Pittsburgh
Don C. Dailey, Austin Peay State University
Douglas W. Darnowski, Indiana University—Southeast
Garry Davies, University of Alaska
Renee Dawson, University of Utah
Lewis E. Deaton, University of Louisiana—Lafayette
Tom Deaton, Auburn University
Elizabeth Anne Desy, Southwestern Minnesota State
University
Doreen R. Dewell, Whatcom Community College
Mary E. Dominiecki, Slippery Rock University
Charles Dunn, Austin Community College
Frank DuRoy, Essex County College
Kari Eamma, Tarrant County Community College
—Northeast
Heidi Engelhardt, Brandon University
Marirose T. Ethington, Genesee Community College
Rebecca A. Fetherson, University of Dayton
Robert C. Frankis, University of New Mexico
Monica C. Frazier, Columbus State University
Anne Galbraith, University of Wisconsin—La Crosse
Sandra Gibbons, Moraine Valley College
Phillip G. Gibson, Gwinnett Technical College
Andrew Golszsek, North Carolina A & T State University
Stephen M. Gómez, Central New Mexico Community
College
Becky C. Graham, University of West Alabama
Cara Gubbins, Butte College
Charles (Billy) Gunnels IV, Florida Gulf Coast University

Janelle M. Hare, Morehead State University
Carla Hass, Pennsylvania State University
Colleen Hatfield, California State University—Chico
J. L. Henriksen, Bellevue Community College
John A. Hnida, Peru State College
Thomas Horvath, State University of New York—Oneonta
Adam W. Hrinkevich, Louisiana State University
Dianne Jennings, Virginia Commonwealth University
Mitrick A. Johns, Northern Illinois University
Robert D. Johnson Jr., Pierce College
Martin A. Kapper, Central Connecticut State University
Arnold J. Karpoff, University of Louisville
Todd Kelson, Brigham Young University—Idaho
Stephen T. Kenny, Yakima Valley Community College
Jennifer M. Kilbourne, Community College of
Baltimore County
Joanne Kilpatrick, Auburn University—Montgomery
Brenda Knotts, Eastern Illinois University
Michael Koban, Morgan State University
Catherine Koo, Caldwell College
Jerome A. Krueger, South Dakota State University
Jim Krupa, University of Kentucky
Ellen Shepard Lamb, University of North Carolina
at Greensboro
Thomas Landefeld, California State University—Dominquez
Hills
Leah LaPerle Larkin, University of New Mexico
Lynn Larsen, Portland Community College
Kathleen H. Lavoie, State University of New York—
Plattsburgh
Gregory P. Lewis, Furman University
Harvey Liftin, Broward Community College
Tammy J. Liles, Lexington Community College
Cynthia W. Littlejohn, University of Southern Mississippi
Jonathan Lochamy, Georgia Perimeter College
Melanie Loo, California State University—Sacramento
Juan M. Lopez-Bautista, University of Alabama
Blasé Maffia, University of Miami
Jeffrey M. Marcus, Western Kentucky University
Betsy Maxim, Austin Community College
Karen McFarland, Austin Peay State University
Mark A. McGinley, Texas Technical University
John Mersfelder, Sinclair Community College
Shahroukh Mistry, Westminster College
Jeanne Mitchell, Truman State University
Beth A. Montelone, Kansas State University
Cynthia L. Morin, Lincoln University of Missouri
Royden Nakamura, California Polytechnic—San Luis Obispo
Rocky Nation, Southern Wesleyan University
Allan D. Nelson, Tarleton State University
Tania Nezrick, Kishwaukee College
David Niebuhr, College of William and Mary
Meredith Sommerville Norris, University of North Carolina
at Charlotte
Alexander E. Olvido, Virginia State University
Randi Papke, Southwestern Illinois College
Mary Paulson, Central Washington University
John M. Pleasants, Iowa State University
Gregory J. Podgorski, Utah State University
Melissa Presch, California State University—Fullerton

Eric Rabitoy, Citrus College
Karen Raines, Colorado State University
Dawn Ranish, Nova Southeastern University
Erin Rempala, San Diego Mesa College
Melody Ricci, Victor Valley
Kathleen Richardson, Portland Community College
Dave Rintoul, Kansas State University
Steven Rissing, The Ohio State University
Robert R. Robbins, Utah Valley State College
Bill Rogers, Ball State University
Troy T. Rohn, Boise State University
Susan T. Rouse, Southern Wesleyan University
Lynette Rushton, South Puget Sound Community College
Michael L. Rutledge, Middle Tennessee State University
Shamili Ajgaonkar Sandiford, College of DuPage
Fayla Schwartz, Everett Community College
Erik P. Scully, Towson University
Juanita C. Sharpe, Chicago State University
Marilyn Shopper, Johnson County Community College
Michele Shuster, New Mexico State University
Neil E. Simister, Brandeis University
Anu Singh-Cundy, Western Washington University
Jennifer Skillen, College of Southern Nevada
Kerri M. Skinner, University of Nebraska—Kearny
Marc Allen Smith, Sinclair Community College
Nancy G. Solomon, Miami University of Ohio
Roberta Lynn Soltz, Central Washington University
Bryan G. Spohn, Florida Community College at Jacksonville—
Kent Campus
Amanda Starnes, Emory University
Leo Sternberg, University of Miami
Joan C. Stover, South Seattle Community College
Sukanya V. Subramanian, Collin County Community College
Franklyn Tan Te, Miami Dade Community College
William J. Thieman, Ventura College
Pamela Thinesen, Century College
Michael W. Thompson, Middle Tennessee State University
Martin A. Vaughan, Indiana University—Purdue University
Indianapolis
Jack Waber, West Chester University of Pennsylvania
Jennifer M. Warner, University of North Carolina at Charlotte
John E. Whitlock, Hillsborough Community College
Elizabeth Willott, University of Arizona
Clifford Wilson, Chicago State University
Mark Woelfle, Vanderbilt University
Calvin Young, Fullerton College
Brenda Zink, Northeastern Junior College

First Edition Art Development

Ann Aguanno, Marymount Manhattan College
Kelly Carrillo Burke, College of the Canyons
William Caire, University of Central Oklahoma
Debra Chapman, Wilkes University
Genevieve C. Chung, Broward Community College
Jeffrey Scott Coker, Elon University
Michael S. Dann, Pennsylvania State University
Renee Dawson, University of Utah

Francisco Delgado, Pima Community College
Doreen R. Dewell, Whatcom Community College
Hartmut G. Doebel, George Washington University
Diane Lynn Doidge, Grand View College
James Doyle, College of the Holy Cross
Dave Eakin, Eastern Kentucky University
Paul Farnsworth, University of New Mexico
Brandon L. Foster, Wake Technical and Community College
Patrick Galliard, North Iowa Community College
David Gordon, Pittsburg State University
Charles (Billy) Gunnels IV, Florida Gulf Coast University
Bernard Hauser, University of Florida
Jane J. Henry, Baton Rouge Community College
Mark A. Holland, Salisbury University
Virginia E. Irintcheva, Black Hawk College—Quad City Campus
Philip Jardim, City College of San Francisco
Denim M. Jochimsen, University of Idaho
Judy Kaufman, Monroe Community College
Ariel R. Krakowski, Laney College
Dan E. Krane, Wright State University
Maria Kretzman, Glendale College
Kathleen H. Lavoie, State University of New York—Plattsburgh
Mary LeFever, Columbus State Community College
Stephen Matheson, Calvin College
James McCaughern-Carucci, Quinnipiac University
Lori A. Pitkofsky, Rampano College
Michael P. Robinson, Miami University
Wendy F. Rothwell, University of California—Santa Cruz
Jason F. Schreer, State University of New York—Potsdam
Jennifer J. Scoby, Illinois Central College
Dawn Sherry, Macon State University
Cara Shillington, Eastern Michigan University
Patricia L. Smith, Valencia Community College
Jeffrey Thomas, California State University—Northridge
Bruce Tomlinson, State University of New York—Fredonia
Joy B. Trauth, Arkansas State University
Alan R. Wasmoen, Metropolitan Community College
Michael Windelspecht, Appalachian State University
David E. Wolfe, American River College
Kerry Yurewicz, Plymouth State University

First Edition Accuracy Reviewers

Christine Bezotte, Elmira College
Michael Carr, Oakton Community College
Erica Champion
William Crampton, University of Central Florida
Michael S. Dann, Pennsylvania State University
Bernard Hauser, University of Florida
John A. Hnida, Peru State College
Kelly Hogan, University of North Carolina at Chapel Hill
Anne Houtman, California State University—Fullerton
Ariel R. Krakowski, Laney College
Michael Silva, El Paso Community College
Pamela Thinesen, Century College
Jeffrey Thomas, California State University—Northridge

Michael Wenzel, California State University—Sacramento
John E. Whitlock, Hillsborough Community College

First Edition Focus Group Attendees Text and Content Development

(2004, Los Angeles)

Garen Baghdasarian, Santa Monica College
Thomas Chen, Santa Monica College
Elizabeth Ciletti, Pasadena City College
Mary Colavito, Santa Monica College
Ana Ester Escandon, Los Angeles Harbor College
Phyllis Hirsh, East Los Angeles College
Melody Ricci, Victor Valley College

(2004, Memphis)

T. Wayne Barger, Tennessee Technical University
Don Baud, University of Memphis
Jay Blundon, Rhodes College
Martha P. Brown, University of Memphis
Dave Eakin, Eastern Kentucky University
Stan Eisen, Christian Brothers University
Jack Grubaugh, University of Memphis
Min-Ken Lao, Furman University

(2004, Chicago)

Sandra Bobick, Community College of Allegheny
Christopher Dobson, Grand Valley State University
Sondra Dubowsky, Allen County Community College
Eileen Gregory, Rollins College
Tracy Harris, Florida Keys Community College
Robert Krasner, Providence College
Bernard A. Marcus, Genesee Community College
Laurel B. Roberts, University of Pittsburgh
Lyndell P. Robinson, Lincoln Land Community College
Brian Schmaefsky, Kingwood College
Janet Vigna, Grand Valley State University
Daniel W. Ward, Waubensee Community College

(2006, Florida)

Peggy Brickman, University of Georgia
Anne E. Bunnell, East Carolina University
Cara Gubbins, Butte College
Janelle M. Hare, Morehead State University
John A. Hnida, Peru State College
Mitrick A. Johns, Northern Illinois University
Kathleen H. Lavoie, State University of New York—Plattsburgh
Blasé Maffia, University of Miami
Gregory J. Podgorski, Utah State University
Susan T. Rouse, Southern Wesleyan University
Jennifer M. Warner, University of North Carolina at Charlotte

Art Development

(2007, Atlanta)

Renee Dawson, University of Utah
Charles (Billy) Gunnels IV, Florida Gulf Coast University
Bernard Hauser, University of Florida

Arnold J. Karpoff, University of Louisville
Stephen R. Kelso, University of Illinois at Chicago
Meredith Sommerville Norris, University of North Carolina at Charlotte
Therese M. Poole, Georgia State University
Mary Celeste Reese, Mississippi State University
Bill Rogers, Ball State University
Kim Cleary Sadler, Middle Tennessee State University
Amy S. Wernette, Hazard Community College

Media and Supplements

(2007, Santa Monica)

Michael Bucher, College of San Mateo
Kelly Carrillo Burke, College of the Canyons
John A. Hnida, Peru State College
Anne Houtman, California State University—Fullerton
Hinrich Kaiser, Victor Valley College
Melanie Loo, California State University—Sacramento
Gregory J. Podgorski, Utah State University
Melissa Presch, California State University—Fullerton
Calvin Young, Fullerton College

(2008, Miami)

Barbara Blonder, Flagler College
Charlotte Borgeson, University of Nevada—Reno
Kris Curran, University of Wisconsin—Whitewater
Kari Eamma, Tarrant Community College
Evelyn Frazier, Florida Atlantic University
John Janovy, University of Nebraska—Lincoln
Jennifer Schramm, Chemeketa Community College
Greg Sievert, Emporia University
Heather Vance Chalcraft, East Carolina University
Martin Vaughn, Indiana University—Purdue University Indianapolis

First Edition Comparative Reviewers

Zulfiqar Ahmad, East Tennessee State University
Julie H. Aires, Florida Community College at Jacksonville
Mahmood Anwar, Palm Beach Community College
William Anyonge, Xavier University
Tami Asplin, North Dakota State University
Christine Barrow, Prince George's Community College
Joressia Beyer, John Taylor Community College
Randy Brewton, University of Tennessee—Knoxville
Dustin Brisson, University of Pennsylvania
Jeannie Chapman, University of South Carolina—Upstate
Thomas Chen, Santa Monica College
Cary Chevalier, Missouri Western State University
Craig Clifford, Northeastern State University
Vince Connors, University of South Carolina—Upstate
William Gareth Richard Crampton, University of Central Florida
Chris Davison, Long Beach City College
Kevin Dees, Wharton City Junior College
Doreen Dewell, Whatcom Community College
Tiffany Doan, Central Connecticut State University
Ernest F. DuBrul, University of Toledo

Eugene Fenster, Metropolitan Community College—Longview
Rebecca Fetherson, University of Dayton
Teresa G. Fischer, Indian River State College
Anita Pardue Flick, North Carolina State University
Paul Florence, Jefferson Community and Technical College
Evelyn Frazier, Florida Atlantic University
Diane Wilkening Fritz, Northern Kentucky University
Dennis W. Fulbright, Michigan State University
Douglas C. Gayou, University of Missouri—Columbia
Bagie George, Georgia Gwinnett College
Betsy Gerbec, University of Wisconsin—River Falls
Oliver Ghobrial, Santa Fe College
Julie Gibbs, College of DuPage
Florence K. Gleason, University of Minnesota
Bruce Griffis, Kentucky State University
Tim Grogan, Valencia Community College
Charles J. Grossman, Xavier University
Luis S. Guerra, South Texas College
Pieter de Haan, Berkeley City College
Pamela Hanratty, Indiana University at Bloomington
Mary F. Haskins, Rockhurst University
Keith R. Hench, Kirkwood Community College
Sherry Hickman, Hillsborough Community College
Mark Hollier, Georgia Perimeter College
Robert A. Holmes, Hutchinson Community College
Laurie Host, Harford Community College
Tamalene Imbierowicz, Harford Community College
Robert Iwan, Inver Hills Community College
Philip Jardim, City College of San Francisco
Dianne Jennings, Virginia Commonwealth University
Greg Jones, Santa Fe College
David Knowles, East Carolina University
Janice Krumm, Widener University
Kim Lackey, University of Alabama
Ellen Lamb, University of North Carolina at Greensboro
David Loring, Johnson County Community College
Bill Mackay, Edinboro University of Pennsylvania
Christi Magrath, Troy University
Barbara Mania-Farnell, Purdue University—Calumet
Tom J. McConnell, Ball State University
Wallace M. Meyer, College of the Redwoods
Thelma Miller-Anderson, Hillsborough Community College
Michael R. Millward, University of Cincinnati
Shahroukh Mistry, Westminster College
Brenda Moore, Truman State University
Michael Muller, University of Illinois at Chicago
Zia Nisani, Antelope Valley College
Tanya Noel, York University
James Nolan, Georgia Gwinnett College
Laura Palmer, Pennsylvania State University—Altoona
Louis Pech, University of Wisconsin Centers—Marathon County
Joel B. Piperberg, Millersville University
Karen Plucinski, Missouri Southern State University

Aggie Posthumus, Olivet Nazarene University
Bob Pozos, San Diego State University
Raul Ramirez, Oklahoma City Community College
Bonnie Ripley, Grossmont College
Troy Rohn, Boise State University
Matthew Rowe, Sam Houston State University
Yelena Rudayeva, Palm Beach Community College
Arthur Sandquist, Washburn University
Craig Scott, Clarion University of Pennsylvania
Wallace Sharif, Morehouse College
Donald Slish, Plattsburgh State University
Anthony J. Stancampiano, Oklahoma City Community College
Christine Stracey, University of Florida
Tim Strakosh, State University of New York—Fredonia
Richard P. Stringer, Harrisburg Area Community College
Mark Sturtevant, Oakland University
Sukanya Subramanian, Collin County Community College
Rob Swatski, Harrisburg Area Community College
Kimberly Taugher, Diablo Valley College
Jeffrey Thornsberry, Northwest Missouri State
Nina Thumser, Indiana University of Pennsylvania
Jonathan Titus, State University of New York—Fredonia
Mike Tveten, Pima Community College Northwest
Linda Tyson, Santa Fe College
Katherine M. Van de Wal, Community College of Baltimore County—Essex Campus
Leslie VanderMolen, Humboldt State University
Fred Vogt, Elgin Community College
William A. Wehbi, University of Pennsylvania
John E. Whitlock, Hillsborough Community College
Jennifer Wiatrowski, Pasco-Hernando Community College
Christina Willis, Rockhurst University
Donald S. Wood, Odessa College
Clarence Wright, Tulsa Community College—Metro Campus
Aimee Wurst, Lincoln University of Missouri
Lan Xu, South Dakota State University

First Edition Class Testers

Questions

Borough of Manhattan Community College
Broward Community College
Central New Mexico Community College
Colorado Mountain College
Florida Community College at Jacksonville
Heartland Community College
Johnson County Community College
Kutztown University of Pennsylvania
Lincoln Land Community College
Metropolitan Community College
Mt. San Jacinto College
Portland State University

Rowan University
Seattle Central Community College
Suffolk County Community College—Ammerman
Tarrant County Community College—Northeast
University of Northern Colorado
Wake Technical Community College

Chapters

(2007)

College of San Mateo
Georgia Perimeter College
Georgia State University
Hazard Community College
Southwestern College
University of Arizona
University of Louisville
University of North Carolina at Charlotte
University of Utah
Utah State University
Virginia Commonwealth University

(2008)

Bluegrass Community College
California State University—Northridge
Chaffey College
Clark Atlanta University
Columbus State University
Daytona Community College
Edinboro University of Pennsylvania
Genesee Community College
George Washington University
Glendale College
Lake Land College
Long Beach Community College
Los Angeles Harbor College
Macon State University
Marshall University
McPherson College
Millersville University of Pennsylvania
Milwaukee Area Technical College
Owensboro Community College
Oxnard College
Philadelphia University
Prince George's Community College
Quinnipiac University
Rock Valley
Sacramento City College
Salem State College
San Jose State University
Sinclair Community College
Southwestern College
St. Clair Community College
University of New Mexico
University of Rhode Island
Valencia Community College

Contributors and Advisors

Instructor's Manual—Classroom Catalysts

Verona A. Barr, Heartland Community College
Stephen M. Gómez, Central New Mexico Community College
Paul H. Marshall, Northern Essex Community College

eBook and Non-Major's Biology Study Tools

Amy Combs
Robert Iwan, Inver Hills Community College
Eric Stavney, Pierce College

Exploring Biology: Case Studies

Michelle Cawthorn, Georgia Southern University
Jennifer L. Holzman, Emory University

Figure Conversion Engine

Ann Aguanno, Marymount Manhattan College

Hands-On Biology: Laboratories for Distance Learning

Mimi Bres, Cassandra Moore-Crawford, and Arnold Weisshaar, Prince George's Community College (all)

Image Bank Advisor

Jane J. Henry, Baton Rouge Community College

Keynote Lecture Presentation

Michael C. Bucher, College of San Mateo

PowerPoint Lecture Outlines

Kristen L. Curran, University of Wisconsin–Whitewater
Danielle DuCharme, Waubesa Community College
Jennifer Lange, Chabot College
Mark S. Manteuffel, St. Louis Community College

Prep-U Instructor's Test Bank and Prep-U for Students

Glenn Adelson, Lake Forrest College
Jay Phelan, University of California, Los Angeles
Alon Ziv, Prep-U

Animations

Anne Bunnell, East Carolina University
G. Chung, Broward College
Johnny El-Rady, University of South Florida
Julie V. Gibbs, College of DuPage
Eric Stavney, North Seattle Community College

Student Worksheets

Michael C. Bucher, College of San Mateo

Reviewers

Ann Aguanno, Marymount Manhattan College
Charlotte E. Borgeson, University of Nevada–Reno
Kelly Burke, College of the Canyons
Michelle Cawthorn, Georgia Southern University
Michael S. Dann, Pennsylvania State University
Debra B. Folsom, Pasadena City College
Julie V. Gibbs, College of DuPage
Stephen M. Gómez, Central New Mexico Community College
Jane J. Henry, Baton Rouge Community College
Jane Hurlings, Saddleback College
Carina Endres Howell, Lock Haven University
John Janovy, Jr., University of Nebraska–Lincoln
Hinrich Kaiser, Victor Valley College
Judy Kaufman, Monroe Community College
Charlease Kelly-Jackson, Claflin University
Patrick J. Lewis, Sam Houston State University
Cindy S. Malone, California State University–Northridge
Meredith S. Norris, University of North Carolina at Charlotte
Greg Podgorski, Utah State University
Lawrence F. Roberge, Florida Community College at Jacksonville
William D. Rogers, Ball State University
Georgianna Saunders, Missouri State University
Jason Schreer, State University of New York–Potsdam
Marilyn Shopper, Johnson County Community College
Carol St. Angelo, Hofstra University
Eric Stavney, Pierce College
Alicia Steinhardt, Hartnell College
Jamey Thompson, Hudson Valley Community College
Helen Walter, Diablo Valley College
Jennifer M. Warner, University of North Carolina at Charlotte
Michael Windelspecht, Appalachian State University



**Your best pathway to
understanding the world**

1

Scientific Thinking

1.1–1.3 Science is a collection of facts and a process for understanding the world.

- 1.1** What is science? What is biology?
- 1.2** Biological literacy is essential in the modern world.
- 1.3** The scientific method is a powerful approach to understanding the world.

1.4–1.10 A beginner's guide: what are the steps of the scientific method?

- 1.4** Thinking like a scientist: how do you use the scientific method?
- 1.5** Step 1: Make observations.
- 1.6** Step 2: Formulate a hypothesis.
- 1.7** Step 3: Devise a testable prediction.
- 1.8** Step 4: Conduct a critical experiment.
- 1.9** Step 5: Draw conclusions, make revisions.
- 1.10** When do hypotheses become theories, and what are theories?

1.11–1.13 Well-designed experiments are essential to testing hypotheses.

- 1.11** Controlling variables makes experiments more powerful.
- 1.12** Repeatable experiments increase our confidence.
- 1.13** We've got to watch out for our biases.

1.14–1.17 Scientific thinking can help us make wise decisions.

- 1.14** Visual displays of data can help us understand and explain phenomena.
- 1.15** Statistics can help us in making decisions.
- 1.16** Pseudoscience and misleading anecdotal evidence can obscure the truth.
- 1.17** There are limits to what science can do.

1.18 On the road to biological literacy: what are the major themes in biology?

- 1.18** A few important themes tie together the diverse topics in biology.
-

1.1–1.3 Science is a collection of facts and a process for understanding the world.



Already a scientist? It starts with curiosity.

1.1 What is science? What is biology?

You are already a scientist. You may not have realized this yet, but it's true. Because humans are curious, you have no doubt asked yourself or others questions about how the world works and wondered how you might find the answers.

- Does the radiation released by cell phones cause brain tumors?
- Do large doses of vitamin C reduce the likelihood of getting a cold?

These are important and serious questions. But you've probably also pondered some less weighty issues, too.

- Why is morning breath so stinky? And can you do anything to prevent it?
- Why is it easier to remember gossip than physics equations?

And if you really put your mind to the task, you will start to find questions all around you whose answers you might like to know (and some whose answers you'll learn as you read this book).

- Which parent determines a baby's sex? Why?
- Why do so few women get into barroom brawls?
- What is "blood doping," and does it really improve athletic performance?

- Why is it so much easier for an infant to learn a complex language than it is for a college student to learn biology?

Still not convinced you're a scientist? Here's something important to know: science doesn't require advanced degrees or secret knowledge dispensed over years of technical training. It does, however, require an important feature of our species: a big brain, as well as curiosity and a desire to learn. But curiosity, casual observations, and desire can take you only so far. Many pressing issues require some understanding of science, what it can and can't do, and what it can and can't explain. Consider, for example, nutritional claims on foods and dietary supplements, human behavior, health and disease, the interactions of plants, animals, and their environments, global climate change, the continuity and diversity of life in all its forms. By learning more about science, you can understand your life and the world around you.

Explaining how something works or why something happens requires methodical, objective, and rational observations and analysis that are not clouded with emotions or preconceptions. **Science** is not simply a body of knowledge or a list of facts to be remembered. It is an intellectual activity, encompassing observation, description, experimentation, and explanation of natural phenomena. Put another way, science is a pathway by which we can come to discover and better understand our world.

Later in this chapter, we explore specific ways in which we can most effectively use scientific thinking in our lives. But first let's look at a single powerful question that underlies scientific thinking:

How do you know that is true?

Once you begin asking this question—of others and of yourself—you are on the road to a better understanding of the world.

The following two stories about popular and successful products show the importance of questioning the truth of many “scientific” claims you see on merchandise packages or read in a newspaper or on the internet.

Dannon yogurt. According to the Federal Trade Commission (FTC), a U.S. government agency with the mission of consumer protection, the Dannon Company claimed in nationwide advertisements that its Activia yogurt relieves irregularity and helps with “slow intestinal transit time.” Dannon also claimed that its DanActive dairy drink helps prevent colds and flu (FIGURE 1-1). The FTC charged that the ads were deceptive because there was no substantiation for the claims and, further, that the claims had been clinically proven to be false. In an agreement finalized in 2011, Dannon agreed to pay \$21 million in fines and to stop making those claims unless the company gets reliable scientific evidence demonstrating that the claims are true.

Airborne. For almost 15 years, the product Airborne has been marketed and sold to millions of customers. On the packaging and in advertisements, the makers originally asserted that Airborne tablets could ward off colds and boost

your immune system (see Figure 1-1). Not surprisingly, Airborne quickly became a great success; it has generated more than \$200 million in revenue. Then some consumers posed a reasonable question to the makers of Airborne: *How do you know that it wards off colds?*

Can we trust the packaging claims that companies make?

Q To prove their claims, the makers of Airborne pointed to the results of a “double-blind, placebo-controlled study” conducted by a company specializing in clinical drug trials. We’ll discuss exactly what those terms mean later in the chapter; for now we just need to note that as a result of a class-action lawsuit, it became clear that no such study had been conducted and that there was *no* evidence to back up Airborne’s claims. The Airborne company removed the claims from the packaging and agreed to refund the purchase price to anyone who had bought Airborne. It also removed any reference to its “clinical trials,” with the company’s CEO saying that people “are really not scientifically minded enough to be able to understand a clinical study.”

Are you insulted by the CEO’s assumption about your intelligence? You should be. Did you or your parents fall for Airborne’s false claims? Possibly. But here’s some more good news: you can learn to be skeptical and suspicious (in a good way) of product claims. You can learn exactly what it means to have scientific proof or evidence that something is absolutely true. And you can learn this by learning what it means to think scientifically.

Scientific thinking is important in the study of a wide variety of topics: it can help you understand economics, psychology, history, and many other subjects. Our focus in



FIGURE 1-1 Some products claim to improve our health, but how do we know whether they work?

this book is **biology**, the study of living things. Taking a scientific approach, we investigate the facts and ideas in biology that are already known and study the process by which we come to learn new things. As we move through the four parts of the book, we explore the most important questions in biology.

- What is the chemical and physical basis for life and its maintenance?
- How do organisms use genetic information to build themselves and to reproduce?
- What are the diverse forms that life on earth takes, and how has that diversity arisen?
- How do organisms interact with each other and with their environment?

In this chapter, we explore how to think scientifically and how to use the knowledge we gain to make wise decisions. Although we generally restrict our focus to biology, scientific

thinking can be applied to nearly every endeavor, so in this chapter we use a wide range of examples—including some from beyond biology—as we learn how to think scientifically. Although the examples vary greatly, they all convey a message that is key to scientific thinking: it's okay to be skeptical.

Fortunately, learning to think scientifically is not difficult—and it can be fun, particularly because it is so empowering. **Scientific literacy**, a general, fact-based understanding of the basics of biology and other sciences, is increasingly important in our lives, and literacy in matters of biology is especially essential.

TAKE-HOME MESSAGE 1-1

Through its emphasis on objective observation, description, and experimentation, science is a pathway by which we can discover and better understand the world around us.

1.2 Biological literacy is essential in the modern world.

A brief glance at any magazine or newspaper will reveal just how much scientific literacy has become a necessity (**FIGURE 1-2**). Many important health, social, medical, political, economic, and legal issues pivot on complex scientific data and theories. For example, why are unsaturated fats healthier for you than saturated fats? And why do allergies strike

children from clean homes more than children from dirty homes? And why do new agricultural pests appear faster than new pesticides?

As you read and study this book, you will be developing **biological literacy**, the ability to (1) use the process of



FIGURE 1-2 In the news. Every day, news sources report on social, political, medical, and legal issues related to science.

scientific inquiry to think creatively about real-world issues that have a biological component, (2) communicate these thoughts to others, and (3) integrate these ideas into your decision making. Biological literacy doesn't involve just the big issues facing society or just abstract ideas. It also matters to you personally. Should you take aspirin when you have a fever? Are you using the wrong approach if you try to lose weight and, after some initial success, you find your rate of weight loss diminishing? Is it a good idea to consume moderate amounts of alcohol? Lack of biological literacy will put you at the mercy

of “experts” who may try to confuse you or convince you of things in the interest of (their) personal gain. Scientific thinking will help you make wise decisions for yourself and for society.

TAKE-HOME MESSAGE 1·2

Biological issues permeate all aspects of our lives. To make wise decisions, it is essential for individuals and societies to attain biological literacy.

1·3 The scientific method is a powerful approach to understanding the world.

It's a brand new age, and science, particularly biology, is everywhere. To illustrate the value of scientific thinking in understanding the world, let's look at what happens in its absence, by considering some unusual behaviors in the common laboratory rat.

Rats can be trained, without much difficulty, to push a lever to receive a food pellet from a feeding mechanism (FIGURE 1-3). When the mechanism is altered so that there is a 10-second delay between the lever being pushed and the food pellet being dispensed, however, strange things start to happen. In one cage, the rat will push the lever and then, very methodically, run and push its nose into one corner of the cage. Then it moves to another corner and again pushes its nose against the cage. It repeats this behavior at the third and fourth corners of the cage, after which the rat stands in front of the feeder and the pellet is dispensed. Each time the rat pushes the lever it repeats the nose-in-the-corner sequence before moving to the food tray.

In another cage, with the same 10-second delay before the food pellet is dispensed, a rat pushes the lever and then proceeds to do three quick back-flips in succession. It then moves to the food tray for the food pellet when the 10 seconds have elapsed. Like the nose-in-the-corner rat, the back-flip rat will repeat this exact behavior each time it pushes the lever.

Why do people develop superstitions? Can animals be superstitious?



In cage after cage of rats with these 10-second-delay food levers, each rat eventually develops its own peculiar series of behaviors before moving to the food dish to receive the pellet. Why do they do this? Because it seems to work!

They have discovered a method by which they can get a food pellet. To some extent, the rats' behaviors are reasonable. They



FIGURE 1-3 “In the absence of the scientific method . . .” Rats develop strange, superstition-like behaviors if there is a 10-second delay between when they push a lever and when food is delivered.

associate two events—pushing the lever and engaging in some sequence of behaviors—with another: receiving food. In a sense, they have taken a step toward understanding their world, even though the events are not actually related to each other.

Humans can also mistakenly associate actions with outcomes in an attempt to understand and control their world. The irrational belief that actions that are not logically related to a course of events can influence its outcome is called **superstition**. In the absence of scientific thinking, individuals can develop incorrect ideas, such as superstitions about how the world works (FIGURE 1-4). For example, Nomar Garciaparra, a former major league baseball player, always engaged in a precise series of toe taps and adjustments to his batting gloves before he would bat.

Thousands of different narratives, legends, fairy tales, and epics from all around the globe exist to help people understand the

world around them. These stories explain everything from birth and death to disease and healing.

As helpful and comforting as stories and superstitions may be (or seem to be), they are no substitute for really understanding how the world works. This kind of understanding begins when someone wonders about why something is the way it is and then decides to try to find out the answer. This process of examination and discovery is called the **scientific method**.

The scientific method usually begins with someone observing a phenomenon and proposing an explanation for it. Next, the proposed explanation is tested through a series of experiments. If the experiments reveal that the explanation is accurate, and if the experiments can be done by others with the same result, then the explanation is considered to be valid. If the experiments do not support the proposed explanation, then the explanation must be revised or alternative explanations that more closely reflect the experimental results must be proposed and tested. This process continues as better, more accurate explanations are found.

While the scientific method reveals much about the world around us, it doesn't explain everything. There are many other methods through which we can gain an understanding of the world. For example, much of our knowledge about plants and animals does not come from the use of the scientific method, but rather comes from systematic, orderly observation, without the testing of any explicit hypotheses. Other disciplines also involve understandings of the world based on non-scientific processes. Knowledge about history, for example, comes from the systematic examination of past events as they relate to humans, while the "truths" in other fields, such as religion, ethics, and even politics, often are based on personal faith, traditions, and mythology.

Scientific thinking can be distinguished from these alternative ways of acquiring knowledge about the world in that it is **empirical**. Empirical knowledge is based on experience and observations that are rational, testable, and repeatable. The empirical nature of the scientific approach makes it self-correcting: in the process of analyzing a topic, event, or phenomenon with the scientific method, incorrect ideas are discarded in favor of more accurate explanations. In the next sections, we look at how to put the scientific method into practice.



FIGURE 1-4 Superstitions abound. As comforting as myths and superstitions may be, they are no substitute for really understanding how the world works.

TAKE-HOME MESSAGE 1-3

There are numerous ways of gaining an understanding of the world. Because it is empirical, rational, testable, repeatable, and self-correcting, the scientific method is a particularly effective approach.

1.4–1.10 A beginner's guide: what are the steps of the scientific method?



Scientific thinking relies on rational, testable, and repeatable observations. (Shown here: A botanist in Borneo measures *Rafflesia arnoldii*, which produces the largest flowers of any species.)

1.4 Thinking like a scientist: how do you use the scientific method?

“Scientific method”—this term sounds like a rigid process to follow, much like following a recipe. In practice, however, the scientific method is an adaptable process that can be done effectively in numerous ways. This flexibility makes the scientific method a powerful process that can be used to explore a wide variety of thoughts, events, or phenomena, not only in science but in other areas as well.

The basic steps in the scientific method are:

- Step 1.** Make observations.
- Step 2.** Formulate a hypothesis.
- Step 3.** Devise a testable prediction.
- Step 4.** Conduct a critical experiment.
- Step 5.** Draw conclusions and make revisions.

Once begun, though, the process doesn't necessarily continue linearly through the five steps until it is concluded (**FIGURE 1-5**). Sometimes, observations made in the first step can lead to more than one hypothesis and several

testable predictions and experiments. And the conclusions drawn from experiments often suggest new observations, refinements to hypotheses, and, ultimately, increasingly precise conclusions.

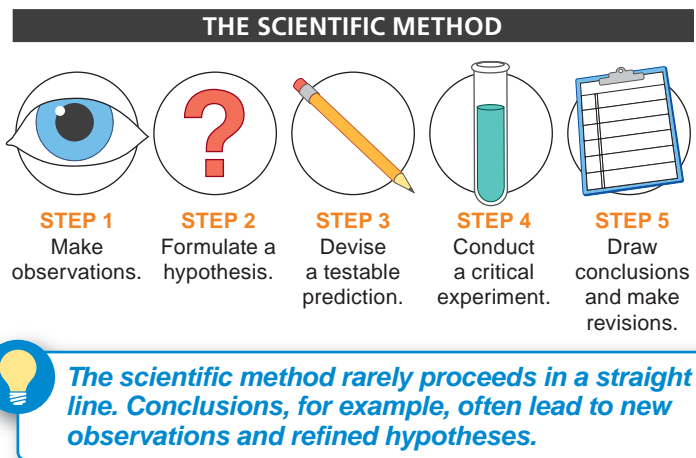


FIGURE 1-5 The scientific method: five basic steps and one flexible process.

What should you do when something you believe in turns out to be wrong?



An especially important feature of the scientific method is that its steps are self-correcting. As we continue to make new observations, a hypothesis about how the world works might change (FIGURE 1-6). If our observations do not support our current hypothesis, that hypothesis must be given up in favor of one that is not contradicted by any

observations. This may be the most important feature of the scientific method: *it tells us when we should change our minds.*

“If science proves some belief of Buddhism wrong, then Buddhism will have to change.”

—THE 14TH DALAI LAMA,
New York Times, December 2005

Because the scientific method is a general strategy for learning, it needn't be used solely to learn about nature or scientific things. In fact, we can analyze an important criminal justice question using the scientific method:

- How reliable is eyewitness testimony in criminal courts?

For more than 200 years, courts in the United States have viewed eyewitness testimony as unassailable. Few things are seen as more convincing to a jury than an individual testifying that she can identify the person she saw commit a crime (FIGURE 1-7). But is eyewitness identification always right?



FIGURE 1-6 Hold the fries. We apply an understanding of science when we choose foods from the menu that have fewer calories and less saturated fat.



FIGURE 1-7 “With your own two eyes . . .”? How reliable is eyewitness testimony in criminal courts?

Can the scientific method tell us if whether this perception—or some other commonly held idea—is true? As we describe how to use the scientific method to answer questions about the world, it will become clear that the answer is a resounding *yes*. In the coming sections of this chapter, we also look at how the scientific method can be used to address a variety of issues. In addition to our criminal justice question, we'll answer three additional questions:

- Does echinacea reduce the intensity or duration of the common cold?
- Does chemical runoff give rise to hermaphrodite fish?
- Does shaving hair from your face, legs, or anywhere else cause it to grow back coarser or darker?

TAKE-HOME MESSAGE 1-4

The scientific method (observation, hypothesis, prediction, test, and conclusion) is a flexible, adaptable, and efficient pathway to understanding the world, because it tells us when we must change our beliefs.

1.5 Step 1: Make observations.

Scientific study always begins with observations: we simply look for interesting patterns or cause-and-effect relationships. This is where a great deal of the creativity of science comes from. In the case of eyewitness testimony, DNA technologies have made it possible to assess whether tissue such as hair or blood from a crime scene came from a particular suspect. Armed with these tools, the U.S. Justice Department recently reviewed 28 criminal convictions that had been overturned by DNA evidence. It found that in most of the cases, the strongest evidence against the defendant had been eyewitness identification. The observation here is that many defendants who are later found to be innocent were initially convicted based on eyewitness testimony.

Opportunities for other interesting observations are unlimited. Using the scientific method, we can (and will) also answer our three other questions.

Many people have claimed that consuming extracts of the herb echinacea can reduce the intensity or duration of symptoms of the common cold (FIGURE 1-8). We can ask: how do you know this is true?

- Does taking echinacea reduce the intensity or duration of the common cold?

Some people have noted that chemicals in sewage runoff—particularly those related to the hormone estrogen—seem to cause male fish to turn into hermaphrodites, organisms that have the reproductive organs of both sexes. Is this true?

- Does chemical runoff give rise to hermaphrodite fish?

And finally, some people have suggested that shaving hair from your face, legs, or anywhere else causes the hair to grow back coarser and darker. Is this true?

- Does hair that is shaved grow back coarser or darker?



STEP 1: MAKE OBSERVATIONS

OBSERVATION

To many people, consuming echinacea extract seems to reduce the intensity or duration of symptoms of the common cold.



FIGURE 1-8 The first step of science: making observations about the world.

Using the scientific method, we can answer all of these questions.

TAKE-HOME MESSAGE 1-5

The scientific method begins by making observations about the world, noting apparent patterns or cause-and-effect relationships.

1.6 Step 2: Formulate a hypothesis.

Based on observations, we can develop a **hypothesis** (*pl. hypotheses*), a proposed explanation for observed phenomena. What hypotheses could we make about the eyewitness-testimony observations described in the previous section? We could start with the hypothesis

“Eyewitness testimony is always accurate.” We may need to modify our hypothesis later, but this is a good start. At this point, we can’t draw any conclusions. All we have done is summarize some interesting patterns we’ve seen in a possible explanation.