# EXPLORING THE DIVERSITY OF LIFE

RUSSELL, HERTZ, MCMILLAN FENTON, MAXWELL, HAFFIE, MILSOM, NICKLE, ELLIS

# From Cengage

MindTap empowers students. Personalized content in an easy-to-use interface helps you achieve better grades.



The new MindTap Mobile App allows for learning anytime, anywhere with flashcards, quizzes and notifications.



The MindTap Reader lets you highlight and take notes online, right within the pages, and easily reference them later.



## nelson.com/mindtap

FOURTH CANADIAN EDITION

# EXPLORING THE DIVERSITY OF LIFE BIOLOGGY

Peter J. Russell

Paul E. Hertz

**Beverly McMillan** 

M. Brock Fenton Western University

Denis Maxwell Western University

Tom Haffie Western University

**Bill Milsom** University of British Columbia

Todd Nickle Mount Royal University

Shona Ellis University of British Columbia

With contributions by Ivona Mladenovic, Simon Fraser University

# NELSON

This is an electronic version of the print textbook. Due to electronic rights restrictions, some third party content may be suppressed. The publisher reserves the right to remove content from this title at any time if subsequent rights restrictions require it. For valuable information on pricing, previous editions, changes to current editions, and alternate formats, please visit nelson.com to search by ISBN#, author, title, or keyword for materials in your areas of interest.

# NELSON

#### **Biology, Fourth Canadian Edition**

by Peter J. Russell, Paul E. Hertz, Beverly McMillan, M. Brock Fenton, Denis Maxwell, Tom Haffie, Bill Milsom, Todd Nickle, Shona Ellis

VP, Product Solutions, K–20: Claudine O'Donnell

Senior Publisher, Digital and Print Content: Paul Fam

Marketing Manager: Tia Nguyen

Content Manager: Toni Chahley

Photo and Permissions Researcher: Kristiina Paul

Senior Production Project Manager: Imoinda Romain

Production Service: MPS Limited

COPYRIGHT © 2019, 2016 by Nelson Education Ltd.

Adapted from *Biology*, Fourth Edition, by Peter J. Russell, Paul E. Hertz, and Beverly McMillan, published by Cengage Learning. Copyright ©2017 by Cengage Learning.

Printed and bound in Canada 2 3 4 5 21 20 19 18

For more information contact Nelson Education Ltd., 1120 Birchmount Road, Toronto, Ontario, M1K 5G4. Or you can visit our Internet site at nelson.com

Cognero and Full-Circle Assessment are registered trademarks of Madeira Station LLC. Copy Editor: Frances Robinson

Proofreader: MPS Limited

Indexer: MPS Limited

Design Director: Ken Phipps

Higher Education Design Project Manager: Pamela Johnston

Interior Design Modifications: Ken Cadinouche

Cover Design: Courtney Hellam

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced, transcribed, or used in any form or by any means—graphic, electronic, or mechanical, including photocopying, recording, taping, Web distribution, or information storage and retrieval systems without the written permission of the publisher.

For permission to use material from this text or product, submit all requests online at cengage.com/permissions. Further questions about permissions can be emailed to permissionrequest@cengage.com

Every effort has been made to trace ownership of all copyrighted material and to secure permission from copyright holders. In the event of any question arising as to the use of any material, we will be pleased to make the necessary corrections in future printings. Cover Image: © Seth Casteel

Art Coordinator: Suzanne Peden

Managing Designer: Courtney Hellam

Illustrator(s): Articulate Graphics, Steve Corrigan, Crowle Art Group, Patrick Gnan, Dave McKay, MPS Limited, Allan Moon, Ann Sanderson, Ralph Voltz

Compositor: MPS Limited

#### Library and Archives Canada Cataloguing in Publication

Russell, Peter J., author Biology : exploring the diversity of life / Peter J. Russell, Paul E. Hertz, Beverly McMillan, M. Brock Fenton, University of Western Ontario, Denis Maxwell, University of Western Ontario, Tom Haffie, University of Western Ontario, Bill Milsom, University of British Columbia, Todd Nickle, Mount Royal University, Shona Ellis, University of British Columbia ; with contributions by Ivona Mladenovic, Simon Fraser University. — Fourth Canadian edition.

Includes index. Issued also in 3 volumes. Issued in print and electronic formats. ISBN 978-0-17-671888-6 (hardcover).— ISBN 978-0-17-682709-0 (PDF)

1. Biology—Textbooks. 2. Textbooks. I. Title.

QH308.2.R88 2018 570 C2017-904622-5 C2017-904623-3

ISBN-13: 978-0-17-671888-6 ISBN-10: 0-17-671888-5

For, and because of, our generations of students.





M. B. (Brock) Fenton received his Ph.D. from the University of Toronto in 1969. Since then, he has been a faculty member in biology at Carleton University, then at York University, and then at Western University. In addition to teaching parts of first-year biology, he has also taught vertebrate biology, animal biology, and conservation biology, as well as field courses in the biology and behaviour of bats. He has received awards for his teaching (Carleton University Faculty of Science Teaching Award; Ontario Confederation of University Faculty Associations Teaching Award; and a 3M Teaching Fellowship, Society for Teaching and Learning in Higher Education) in addition to recognition of his work on public awareness of science (Gordin Kaplan Award from the Canadian Federation of Biological Societies; Honorary Life Membership, Science North, Sudbury, Ontario; Canadian Council of University Biology Chairs Distinguished Canadian Biologist Award; The McNeil Medal for the Public Awareness of Science of the Royal Society of Canada; and the Sir Sandford Fleming Medal for public awareness of Science, the Royal Canadian Institute). He also received the C. Hart Merriam Award from the American Society of Mammalogists for excellence in scientific research. Bats and their biology, behaviour, evolution, and echolocation are the topics of his research, which has been funded by the Natural Sciences and Engineering Research Council of Canada (NSERC). In November 2014, Brock was inducted as a Fellow of the Royal Society of Canada.



Denis Maxwell received his Ph.D. from the University of Western Ontario in 1995. His thesis, under the supervision of Norm Hüner, focused on photosynthetic acclimation in green algae. Following his doctorate, he undertook postdoctoral training at the Department of Energy Plant Research Laboratory at Michigan State University, where he studied the function of the mitochondrial alternative oxidase. After taking up a faculty position at the University of New Brunswick in 2000, he moved in 2003 to the Department of Biology at Western University. Denis served as Associate Chair for Undergraduate Education for the Department of Biology from 2009 to 2016. Currently, he is Assistant Dean for the Faculty of Science, with a portfolio that includes Recruitment and First-Year Studies and outreach. He has taught first-year Biology to over 15 000 students, most of the time with Tom Haffie.



**Tom Haffie** is a graduate of the University of Guelph and the University of Saskatchewan in the area of microbial genetics. Tom has devoted his 33-year career at Western University to teaching large biology classes in lecture, laboratory, and tutorial settings. He led the development of the innovative core laboratory course in the Biology program; he was an early adopter of computer animation in lectures; and, most recently, has overseen a deep blended redesign of introductory biology informed by a students-as-partners approach to development. He is the founding coordinator of the biennial Western Conference on Science Education. He holds a University Students' Council Award for Excellence in Teaching, a UWO Edward G. Pleva Award for Excellence in Teaching, a UWO Fellowship in Teaching Innovation, a Province of Ontario Award for Leadership in Faculty Teaching (LIFT), and a Canadian 3M National Teaching Fellowship for excellence in teaching. Tom is currently a Teaching Fellow for Science at Western University.



a professor in the Department of Zoology at the University of British Columbia, where he has taught a variety of courses, including first-year biology, for almost 40 years. His research interests include the evolutionary origins of respiratory processes and the adaptive changes in these processes that allow animals to exploit diverse environments. He examines respiratory and cardiovascular adaptations in vertebrate animals in rest, sleep, exercise, altitude, dormancy, hibernation, diving, and so on. This research contributes to our understanding of the mechanistic basis tion. His research has been funded by NSERC, and he has received several academic awards and distinctions, including the Fry Medal of the Canadian Society of Zoologists, the August Krogh Distinguished Lectorship Award of the American Physiological Society, the Bidder Lecture of the Society for Experimental Biology, and the Izaak Walton Killam Award for Excellence in Mentoring. He has served as the President of the Canadian Society of Zoologists and as President of the International Congress of Comparative Physiology and Biochemistry.



Rmy Note

**Todd Nickle** received his Ph.D. from Oklahoma State University in 1998, and has been teaching biology at Mount Royal University ever since. He advocates Active Learning: students come to class prepared to *work* with material rather than just hear about it. Student preparation involves reading the text and applying the concepts to online exercises, the results of which inform what the next lecture will be about. Class time focusses on exploring connections between concepts and ideas in biology and how they relate to other disciplines, which inspired him to coauthor a handbook for first-year science students (*Science*<sup>3</sup>). His interest in promoting best teaching practices among educators had him confirm the Alberta Introductory Biology Association as an official Society of Alberta; Todd is currently President. His work put him in the first cohort of Full Professors at Mount Royal University in 2012, garnered the 2015 ACIFA Innovation in Teaching Award, and the Distinguished Faculty Award from MRU in 2016.



Shona Ellis (M.Sc., University of British Columbia) is a professor of teaching in the Botany Department and Associate Head of Biology at the University of British Columbia. She developed a keen interest in forests and the ocean growing up on the central coast of British Columbia. As an undergraduate, Professor Ellis pursued her interests in botany and entomology. Her M.Sc. research incorporated tissue culture, phytochemistry, and plant anatomy. As a teaching assistant, she realized a passion for teaching and joined the teaching faculty at the University of British Columbia in 1998. She teaches botany courses that have included nonvascular and vascular plants, economic botany, bryology, and plant systematics, as well as introductory biology. Professor Ellis has taught in a number of settings: large and small lectures, laboratories, and fieldtrips. While she feels the best classroom is outdoors, she integrates online technologies into all her courses; she is an early adopter of online teaching and learning resources. Professor Ellis has received two Killam Teaching Awards and the Charles Edwin Bessey Teaching Award from the Botanical Society of America.





Peter J. Russell received a B.Sc. in Biology from the University of Sussex, England in 1968 and a Ph.D. in Genetics from Cornell University in 1972. He has been a member of the Biology Faculty of Reed College since 1972, and is currently a Professor of Biology, Emeritus. Peter taught a section of the introductory biology course, a genetics course, and a research literature course on molecular virology. In 1987 he received the Burlington Northern Faculty Achievement Award from Reed College in recognition of his excellence in teaching. Since 1986, he has been the author of a successful genetics textbook: current editions are iGenetics: A Molecular Approach, iGenetics: A Mendelian Approach, and Essential iGenetics. Peter's research was in the area of molecular genetics, with a specific interest in characterizing the role of host genes in the replication of the RNA genome of a pathogenic plant virus, and the

Paul E. Hertz was born and raised in New York City. He received a B.S. in Biology from Stanford University in 1972, an A.M. in Biology from Harvard University in 1973, and a Ph.D. in Biology from Harvard University in 1977. While completing field research for the doctorate, he served on the Biology Faculty of the University of Puerto Rico at Rio Piedras. After spending two years as an Isaac Walton Killam Postdoctoral Fellow at Dalhousie University, Paul accepted a teaching position at Barnard College, where he has taught since 1979. He was named Ann Whitney Olin Professor of Biology in 2000, and he received the Barnard Award for Teaching Excellence in 2007. In addition to serving on numerous college committees, Paul chaired Barnard's Biology Department for eight years and served as Acting Provost and Dean of the Faculty from 2011 to 2012. He is the founding Program Director of the Hughes Science Pipeline Project at Barnard, an undergraduate curriculum and research program that has been funded continuously by the Howard

model host. His research has been funded by agencies including the National Institutes of Health, the National Science Foundation, the American Cancer Society, the Department of Defense, the Medical Research Foundation of Oregon, and the Murdoch Foundation. He has published his research results in a variety of journals, including Genetics, Journal of Bacteriology, Molecular and General Genetics, Nucleic Acids Research, Plasmid, and Molecular and Cellular Biology. Peter has a long history of encouraging faculty research involving undergraduates, including cofounding the biology division of the Council on Undergraduate Research, in Washington, D.C. in 1985. He was Principal Investigator/ Program Director of a National Science Foundation Award for the Integration of Research and Education (NSF-AIRE) to Reed College, 1998-2002.

expression of the genes of the virus; yeast was used as the

Hughes Medical Institute since 1992. The Pipeline Project includes the Intercollegiate Partnership, a program for local community college students that facilitates their transfer to four-year colleges and universities. He teaches one semester of the introductory sequence for Biology majors and pre-professional students, lecture and laboratory courses in vertebrate zoology and ecology, and a year-long seminar that introduces first-year students to scientific research. Paul is an animal physiological ecologist with a specific research interest in the thermal biology of lizards. He has conducted fieldwork in the West Indies since the mid-1970s, most recently focusing on the lizards of Cuba. His work has been funded by the NSF, and he has published his research in The American Naturalist, Ecology, Nature, Oecologia, and Proceedings of the Royal Society. In 2010, he and his colleagues at three other universities received funding from NSF for a project designed to detect the effects of global climate warming on the biology of Anolis lizards in Puerto Rico.



Beverly McMillan has been a science writer for more than 25 years. She holds undergraduate and graduate degrees from the University of California, Berkeley, and is coauthor of a college text in human biology, now in its 11th edition. She has also written or coauthored

numerous trade books on scientific subjects and has worked extensively in educational and commercial publishing, including eight years in editorial management positions in the college divisions of Random House and McGraw-Hill.

## VOLUME 1: BIOLOGY OF THE CELL 1

1 Light and Life 5

## UNIT ONE SYSTEMS AND PROCESSES: THE CELL 25

- 2 The Cell: An Overview 25
- 3 Energy and Enzymes 53
- 4 Cell Membranes and Signalling 77
- 5 Cellular Respiration 101
- 6 Photosynthesis 125

## UNIT TWO GENES 149

- 7 Cell Cycles 149
- 8 Genetic Recombination 173
- 9 The Chromosomal Basis of Mendelian Inheritance 199
- 10 Genetic Linkage, Sex Linkage, and Other Non-Mendelian Inheritance Mechanisms 225

## UNIT THREE DNA AND GENE EXPRESSION 251

- 11 DNA Structure, Replication, and Repair 251
- 12 Gene Structure, Expression, and Mutation 277
- 13 Regulation of Gene Expression 307
- 14 DNA Technologies 333
- 15 Genomes 361

## VOLUME 2: EVOLUTION, ECOLOGY, AND THE DIVERSITY OF LIFE 389

## UNIT FOUR EVOLUTION AND CLASSIFICATION 393

- 16 Evolution: The Development of the Theory 393
- 17 Microevolution: Changes within Populations 411
- 18 Speciation and Macroevolution 433
- 19 Systematics and Phylogenetics: Revealing the Tree of Life 453
- 20 Humans and Evolution 477

## UNIT FIVE THE DIVERSITY OF LIFE 493

- 21 Defining Life and Its Origins 493
- 22 Viruses, Viroids, and Prions: Infectious Biological Particles 521
- 23 Bacteria and Archaea 537
- 24 Protists 559

- 25 Fungi 587
- 26 Plants 611
- 27 Animals 643
- 28 Conservation of Biodiversity 719

## UNIT SIX ECOLOGY AND BEHAVIOUR 747

- 29 Population Ecology 747
- 30 Species Interactions and Community Ecology 777
- 31 Ecosystems 813
- 32 Animal Behaviour 845

## THE CHEMICAL AND PHYSICAL FOUNDATIONS OF BIOLOGY (PURPLE PAGES) F-1

## VOLUME 3: SYSTEMS AND PROCESSES 881

## UNIT SEVEN SYSTEMS AND PROCESSES -PLANTS 885

- 33 Organization of the Plant Body 885
- 34 Transport in Plants 913
- 35 Reproduction and Development in Flowering Plants 933
- 36 Plant Nutrition 955
- 37 Plant Signals and Responses to the Environment 977

## UNIT EIGHT SYSTEMS AND PROCESSES -ANIMALS 1007

- 38 Introduction to Animal Organization and Physiology 1007
- 39 Animal Nutrition 1029
- 40 Gas Exchange: The Respiratory System 1057
- 41 Internal Transport: The Circulatory System 1079
- 42 Regulation of the Internal Environment: Water, Solutes, and Temperature 1103
- 43 Control of Animal Processes: Endocrine Control 1135
- 44 Animal Reproduction 1161
- 45 Control of Animal Processes: Neural Control 1199
- 46 Muscles, Skeletons, and Body Movements 1255

APPENDIX A: ANSWERS TO SELF-TEST QUESTIONS A-1 GLOSSARY G-1 INDEX I-1

About the Canadian Authors iv About the U.S. Authors vi Preface xv New to This Edition xix Welcome to *Biology: Exploring the Diversity of Life*, 4Ce xxiv Active Learning xxvi Student and Instructor Resources xxx Acknowledgements xxxii

## VOLUME 1: BIOLOGY OF THE CELL 1

- 1 Light and Life 5
- 1.1 The Physical Nature of Light 6
- 1.2 Light as a Source of Energy 8
- 1.3 Light as a Source of Information 10
- 1.4 The Uniqueness of Light 14
- 1.5 Light Can Damage Biological Molecules 14

Figure 1.19 Research Method Using Spectrophotometry to Determine an Absorption Spectrum 16

- 1.6 Using Light to Tell Time 17
- 1.7 The Role of Light in Behaviour and Ecology 20
- 1.8 Organisms Making Their Own Light: Bioluminescence 21

## UNIT ONE SYSTEMS AND PROCESSES: THE CELL 25

- 2 The Cell: An Overview 25
- 2.1 Basic Features of Cell Structure and Function 26
- 2.2 Prokaryotic Cells 30
- 2.3 Eukaryotic Cells 31

Figure 2.8 Research Method Cell Fractionation 32

- 2.4 Specialized Structures of Plant Cells 43
- 2.5 The Animal Cell Surface 45

## SUMMARY ILLUSTRATION FOR CHAPTER 2 48

- 3 Energy and Enzymes 53
- Energy and the Laws of Thermodynamics 54
- 3.2 Free Energy and Spontaneous Processes 57
- 3.3 Thermodynamics and Life 59
- 3.4 Overview of Metabolism 61

3.5 The Role of Enzymes in Biological Reactions 64

3.6 Factors That Affect Enzyme Activity 67

## SUMMARY ILLUSTRATION FOR CHAPTER 3 72

- 4 Cell Membranes and Signalling 77
- 4.1 An Overview of the Structure of Membranes 78

Figure 4.2 Experimental Research The Frye–Edidin Experiment Demonstrating That the Phospholipid Bilayer Is Fluid 79

## Figure 4.3 Research Method Freeze Fracture 80

- 4.2 The Lipid Fabric of a Membrane 80
- 4.3 Membrane Proteins 82
- 4.4 Passive Membrane Transport 84
- 4.5 Active Membrane Transport 88
- 4.6 Exocytosis and Endocytosis 90
- 4.7 Role of Membranes In Cell Signalling 92

## SUMMARY ILLUSTRATION FOR CHAPTER 4 96

- 5 Cellular Respiration 101
- 5.1 The Chemical Basis of Cellular Respiration 102
- 5.2 Cellular Respiration: An Overview 104
- 5.3 Glycolysis: The Splitting of Glucose 105
- 5.4 Pyruvate Oxidation and the Citric Acid Cycle 106
- 5.5 Oxidative Phosphorylation: Electron Transport and Chemiosmosis 109
- 5.6 The Efficiency and Regulation of Cellular Respiration 114
- 5.7 Oxygen and Cellular Respiration 116

## SUMMARY ILLUSTRATION FOR CHAPTER 5 120

- 6 Photosynthesis 125
- 6.1 Photosynthesis: An Overview 126
- 6.2 The Photosynthetic Apparatus 128
- 6.3 The Light Reactions 132
- 6.4 The Calvin Cycle 134
- 6.5 Photorespiration and CO2-Concentrating Mechanisms 137
- 6.6 Photosynthesis and Cellular Respiration Compared 142

## SUMMARY ILLUSTRATION FOR CHAPTER 6 144

## UNIT TWO GENES 149

- 7 Cell Cycles 149
- 7.1 The Cycle of Cell Growth and Division: An Overview 150
- 7.2 The Cell Cycle in Prokaryotic Organisms 151
- 7.3 Mitosis and the Eukaryotic Cell Cycle 152

viii

## 7.5 Cell Cycle Regulation 162

Figure 7.19 Experimental Research Movement of Chromosomes during Anaphase of Mitosis 164

## SUMMARY ILLUSTRATION FOR CHAPTER 7 168

## 8 Genetic Recombination 173

- 8.1 Mechanism of Genetic Recombination 174
- 8.2 Genetic Recombination in Bacteria 175

Figure 8.2 Research Method Replica Plating 176

Figure 8.3 Experimental Research Genetic Recombination in Bacteria 177

 8.3 Genetic Recombination Occurs in Eukaryotes during Meiosis 183

## SUMMARY ILLUSTRATION FOR CHAPTER 8 194

- 9 The Chromosomal Basis of Mendelian Inheritance 199
- 9.1 The Beginnings of Genetics: Mendel's Garden Peas 200

Figure 9.2 Research Method Making a Genetic Cross between Two Pea Plants 201

Figure 9.4 Experimental Research The Principle of Segregation: Inheritance of Flower Colour in Garden Peas 204

Figure 9.7 Experimental Research Testing the Predicted Outcomes of Genetic Crosses 208

Figure 9.8 Experimental Research The Principle of Independent Assortment 209

9.2 Later Modifications and Additions to Mendel's Hypotheses 212

Figure 9.12 Experimental Research Experiment Showing Incomplete Dominance of a Trait 213

## SUMMARY ILLUSTRATION FOR CHAPTER 9 220

- 10 Genetic Linkage, Sex Linkage, and Other Non-Mendelian Inheritance Mechanisms 225
- 10.1 Genetic Linkage and Recombination 226

Figure 10.2 Experimental Research Evidence for Gene Linkage 228

## 10.2 Sex-Linked Genes 231

Figure 10.8 Experimental Research Evidence for Sex-Linked Genes 234

- 10.3 Chromosomal Mutations That Affect Inheritance 236
- Human Genetic Traits, Pedigree Analysis, and Genetic Counselling 240
- 10.5 Additional Non-Mendelian Patterns of Inheritance 244

### SUMMARY ILLUSTRATION FOR CHAPTER 10 246

11 DNA Structure, Replication, and Repair 251

11.1 Establishing DNA as the Hereditary Molecule 252

Figure 11.1 Experimental Research Griffith's Experiment with Virulent and Nonvirulent Strains of *Streptococcus pneumoniae* 253

Figure 11.2 Experimental Research The Hershey and Chase Experiment Demonstrating That DNA Is the Hereditary Molecule 255

- 11.2 DNA Structure 255
- 11.3 DNA Replication 258

Figure 11.9 Experimental Research The Meselson and Stahl Experiment Demonstrating the Semiconservative Model for DNA Replication to Be Correct 261

11.4 Repair of Damage in DNA 270

## SUMMARY ILLUSTRATION FOR CHAPTER 11 272

- 12 Gene Structure, Expression, and Mutation 277
- 12.1 The Connection between DNA, RNA, and Protein 278

Figure 12.2 Experimental Research The Gene–Enzyme Relationship 280

- 12.2 Transcription: DNA-Directed RNA Synthesis 283
- 12.3 Processing of mRNAs in Eukaryotes 285
- 12.4 Translation: mRNA-Directed Polypeptide Synthesis 289
- 12.5 Mutations Can Affect Protein Structure and Function 299

## SUMMARY ILLUSTRATION FOR CHAPTER 12 302

## 13 Regulation of Gene Expression 307

- 13.1 Regulation of Gene Expression in Prokaryotic Cells 308
- 13.2 Regulation of Transcription in Eukaryotes 314
- 13.3 Posttranscriptional, Translational, and Posttranslational Regulation 321
- 13.4 The Loss of Regulatory Controls in Cancer 325

## SUMMARY ILLUSTRATION FOR CHAPTER 13 328

### 14 DNA Technologies 333

14.1 DNA Cloning 334

Figure 14.3 Research Method Identifying a Recombinant Plasmid Containing a Gene of Interest 337

Figure 14.4 Research Method Synthesis of DNA from mRNA Using Reverse Transcriptase 338

Figure 14.5 Research Method The Polymerase Chain Reaction (PCR) 339

Figure 14.6 Research Method Separation of DNA Fragments by Agarose Gel Electrophoresis 340

14.2 Applications of DNA Technologies 341

NEL

17.5 Figure 14.11 Research Method Making a Knockout Mouse 347

Research in Biology CRISPR: A Programmable RNA-Guided Genome Editing System 348

Figure 14.13 Experimental Research The First Cloning of a Mammal 351

Figure 14.15 Research Method Using the Ti Plasmid of Rhizobium radiobacter to Produce Transgenic Plants 352

## SUMMARY ILLUSTRATION FOR CHAPTER 14 356

#### Genomes 361 15

- 15.1 Genomics: An Overview 362
- 15.2 Genome Sequencing 363
- Figure 15.1 Research Method Sanger Sequencing 364
- Figure 15.2 Research Method Pyrosequencing 368
- 15.3 Annotation Identifies Genes 371

Figure 15.8 Research Method DNA Microarray Analysis of Gene Expression Levels 376

- 15.4 Comparative Genomics Can Reveal How Genes and Genomes Evolved 377
- SUMMARY ILLUSTRATION FOR CHAPTER 15 386

## **VOLUME 2: EVOLUTION, ECOLOGY, AND THE** DIVERSITY OF LIFE 389

## UNIT FOUR EVOLUTION AND CLASSIFICATION 393

#### 16 Evolution: The Development of the Theory 393

- 16.1 The Recognition of Change 394
- 16.2 Natural Selection 397
- 16.3 Evolutionary Biology since Darwin 400
- 16.4 Evolution Is the Core Theory of Modern Biology but Is Plagued by Misconceptions 403

Figure 16.16 Experimental Research Adaptation of E. coli to a Change in Temperature 404

## SUMMARY ILLUSTRATION FOR CHAPTER 16 406

#### Microevolution: Changes within Populations 411 17

- 17.1 Variation in Natural Populations 412
- 17.2 Population Genetics 414
- 17.3 The Agents of Microevolution 416

Figure 17.7 Research Method Using the Hardy–Weinberg Principle 417

Figure 17.12 Experimental Research Do Humans Experience Stabilizing Selection? 422

Maintaining Genetic and Phenotypic Variation 425

Figure 17.16 Experimental Research Sexual Selection in Action 426

## SUMMARY ILLUSTRATION FOR CHAPTER 17 428

- 18 Speciation and Macroevolution 433
- 18.1 What Is a Species? 434
- 18.2 Maintaining Reproductive Isolation 437
- The Geography of Speciation 440 18.3
- 18.4 Genetic Mechanisms of Speciation 443

Figure 18.16 Observational Research Chromosomal Similarities and Differences among Humans and the Great Apes 447

## SUMMARY ILLUSTRATION FOR CHAPTER 18 448

- Systematics and Phylogenetics: Revealing the Tree of 19 Life 453
- Nomenclature and Classification 454 19.1
- Phylogenetic Trees 456 19.2
- Sources of Data for Phylogenetic Analyses 458 19.3
- 19.4 Traditional Classification and Paraphyletic Groups 461
- 19.5 The Cladistic Revolution 462

Figure 19.11 Research Method Using Cladistics to Construct a Phylogenetic Tree 465

Figure 19.13 Research Method Using Genetic Distances to Construct a Phylogenetic Tree 468

- Phylogenetic Trees as Research Tools 469 19.6
- 19.7 Molecular Phylogenetic Analyses 469

## SUMMARY ILLUSTRATION FOR CHAPTER 19 472

#### Humans and Evolution 477 20

Research in Biology The Cast of Characters: Fossil Hominins 478

- 20.1 The Fossil Record of Hominins 480
- Morphology and Bipedalism 481 20.2
- Human Features That Do Not Fossilize 484 20.3
- Dispersal of Early Humans 485 20.4
- Hominins and the Species Concepts 485 20.5

SUMMARY ILLUSTRATION FOR CHAPTER 20 488

## UNIT FIVE THE DIVERSITY OF LIFE 493

- Defining Life and Its Origins 493 21
- 21.1 What Is Life? 494
- The Chemical Origins of Life 494 21.2
- From Macromolecules to Life 499 21.3
- 21.4 Evidence of the Earliest Life 502

CONTENTS

- 21.6 The Fossil Record 507
- 21.7 The Tree of Life 509

Figure 21.23 Research Method Radiometric Dating 511

## SUMMARY ILLUSTRATION FOR CHAPTER 21 516

- 22 Viruses, Viroids, and Prions: Infectious Biological Particles 521
- 22.1 What Is a Virus? Characteristics of Viruses 522
- 22.2 Viruses Infect Bacterial, Animal, and Plant Cells by Similar Pathways 524
- 22.3 Treating and Preventing Viral Infections 528

Figure 22.7 Experimental Research A New Discovery for Hepatitis C Therapy 529

- 22.4 Viruses May Have Evolved from Fragments of Cellular DNA or RNA 530
- 22.5 Viroids and Prions Are Infective Agents Even Simpler in Structure than Viruses 530

## SUMMARY ILLUSTRATION FOR CHAPTER 22 532

#### Bacteria and Archaea 537 23

- 23.1 The Full Extent of the Diversity of Bacteria and Archaea Is Unknown 538
- 23.2 Prokaryotic Structure and Function 538

Figure 23.5 Experimental Research Genetic Recombination in Bacteria 541

- 23.3 The Domain Bacteria 548
- 23.4 The Domain Archaea 550

## SUMMARY ILLUSTRATION FOR CHAPTER 23 554

- Protists 559 24
- The Vast Majority of Eukaryotes Are Protists 560 24.1
- 24.2 Characteristics of Protists 561
- 24.3 Protists' Diversity Is Reflected in Their Metabolism, Reproduction, Structure, and Habitat 562
- 24.4 The Eukaryotic Supergroups and Their Key Protist Lineages 563

Figure 24.8 Observational Research Isolation and Identification of Marine Diplonemids, Potentially the Most Abundant Marine Organism 565

24.5 Some Protist Lineages Arose from Primary Endosymbiosis and Others from Secondary Endosymbiosis 580

## SUMMARY ILLUSTRATION FOR CHAPTER 24 582

- 25 Fungi 587
- General Characteristics of Fungi 588 25.1
- 25.2 Evolution and Diversity of Fungi 590
- 25.3 Fungal Lifestyles 600

## Symbiosis 602

## SUMMARY ILLUSTRATION FOR CHAPTER 25 606

#### 26 Plants 611

- 26.1 Defining Characteristics of Land Plants 612
- 26.2 The Transition to Life on Land 613
- Bryophytes: Nonvascular Land Plants 619 26.3
- Seedless Vascular Plants 622 26.4
- 26.5 Gymnosperms: The First Seed Plants 628
- 26.6 Angiosperms: Flowering Plants 632

Figure 26.30 Experimental Research Exploring a Possible Early Angiosperm Adaptation for Efficient Photosynthesis in Dim Environments 635

## SUMMARY ILLUSTRATION FOR CHAPTER 26 638

#### Animals 643 27

- 27.1 What Is an Animal? 644
- Key Innovations in Animal Evolution 645 27.2
- Molecular Phylogenetics and Classification 649 27.3
- 27.4 The Basal Phyla 650
- The Protostomes 658 27.5
- Lophotrochozoa Protostomes 659 27.6
- 27.7 Ecdysozoa Protostomes 670
- The Deuterostomes 680 27.8

## Research in Biology The Tully Monster 686

- The Origin and Diversification of Vertebrates 687 27.9
- Agnathans: The Jawless Fishes 689 27.10
- Jawed Fishes: Jaws Meant New Feeding Opportunities 690 27.11
- 27.12 Early Tetrapods and Modern Amphibians 696
- The Origin and Mesozoic Radiations of Amniotes 698 27.13
- 27.14 Turtles and Tortoises (Subclass Testudinata) 702
- 27.15 Living Diapsids: Sphenodontids, Squamates, and Crocodylians 702
- 27.16 Birds 704
- 27.17 Mammalia: Monotremes, Marsupials, and Placentals 708

## SUMMARY ILLUSTRATION FOR CHAPTER 27 714

#### 28 Conservation of Biodiversity 719

- The Anthropocene 720 28.1
- Vulnerability to Extinction 721 28.2
- 28.3 Climate Change Can Cause Extinction 725
- Protecting Species 726 28.4
- 28.5 Protecting What? 727
- Conservation and Agriculture 729 28.6
- Contaminating Natural Systems 730 28.7

NEL

## 28.9 Effecting Conservation 737

Figure 28.33 Observational Research Near-Complete Extinction of Small Mammals in Tropical Forest Fragments 738

- 28.10 Human Population: A Root Problem for Conservation 739
- 28.11 Signs of Stress: Systems and Species 739
- 28.12 Taking Action 740

## SUMMARY ILLUSTRATION FOR CHAPTER 28 742

## UNIT SIX ECOLOGY AND BEHAVIOUR 747

- 29 Population Ecology 747
- 29.1 Introduction 749
- 29.2 Population Characteristics 749
- 29.3 Demography 752
- 29.4 Evolution of Life Histories 753
- 29.5 Models of Population Growth 756
- 29.6 Population Regulation 760

Figure 29.17 Experimental Research Evaluating Density-Dependent Interactions between Species 762

- 29.7 Human Administered Population Control 765
- 29.8 Human Population Growth 766
- 29.9 The Future: Where Are We Going? 770
- 29.10 The Pill 770

## SUMMARY ILLUSTRATION FOR CHAPTER 29 772

### 30 Species Interactions and Community Ecology 777

- 30.1 Introduction 778
- 30.2 Symbiosis: Close Associations 779
- 30.3 Energy Intake 782
- 30.4 Defence 784
- 30.5 Competition 788

Figure 30.15 Experimental Research Demonstration of Competition between Two Species of Barnacles 789

Figure 30.16 Experimental Research Gause's Experiments on Interspecific Competition in *Paramecium* 790

Figure 30.19 Experimental Research The Complex Effects of a Herbivorous Snail on Algal Species Richness 792

- 30.6 The Nature of Ecological Communities 793
- 30.7 Community Characteristics 793
- 30.8 Effects of Population Interactions on Community Structure 798
- 30.9 Succession 799
- 30.10 Variations in Species Richness among Communities 804

SUMMARY ILLUSTRATION FOR CHAPTER 30 808

xii CONTENTS

- 31.1 Connections Within and Among Ecosystems 815
- 31.2 Ecosystems and Energy 816
- 31.3 Nutrient Cycling in Ecosystems 823
- 31.4 Carbon: A Disrupted Cycle 830
- 31.5 Ecosystem Modelling 832
- 31.6 Scale, Ecosystems, Species 833
- 31.7 Three Sample Ecosystems 834

## SUMMARY ILLUSTRATION FOR CHAPTER 31 840

## 32 Animal Behaviour 845

- 32.1 Genes, Environment, and Behaviour 846
- 32.2 Instinct 848

Figure 32.5 Experimental Research The Role of Sign Stimuli in Parent–Offspring Interactions 849

- 32.3 Knockouts: Genes and Behaviour 850
- 32.4 Learning 850
- 32.5 Neurophysiology and Behaviour 852
- 32.6 Hormones and Behaviour 853
- 32.7 Neural Anatomy and Behaviour 855
- 32.8 Communication 856
- 32.9 Language: Syntax and Symbols 861
- 32.10 Space 862
- 32.11 Home Range and Territory 862
- 32.12 Migration 863

Figure 32.32 Experimental Research Experimental Analysis of the Indigo Bunting's Star Compass 867

- 32.13 Mates as Resources 868
- 32.14 Sexual Selection 869
- 32.15 Social Behaviour 870
- 32.16 Kin Selection and Altruism 872
- 32.17 Eusocial Animals 874
- 32.18 Human Social Behaviour 876

## SUMMARY ILLUSTRATION FOR CHAPTER 32 878

## THE CHEMICAL AND PHYSICAL FOUNDATIONS OF BIOLOGY (PURPLE PAGES) F-1

What Are the Purple Pages? F-1 Emergent Properties F-1 The Scientific Basis of Biology F-2 Measurement and Scale F-5 The Organization of Matter F-7 Atoms Interact to Produce New Properties F-11 Chemical Bonds F-11 Water F-15 Carbon Compounds F-21

Proteins F-28 Nucleic Acids F-36 History of Earth F-42

## VOLUME 3: SYSTEMS AND PROCESSES 881

## UNIT SEVEN SYSTEMS AND PROCESSES: PLANTS 885

## 33 Organization of the Plant Body 885

- 33.1 Plant Structure and Growth: An Overview 886
- 33.2 The Three Plant Tissue Systems 890

Figure 33.9 Experimental Research Networking the Secondary Cell Wall 893

- 33.3 Primary Shoot Systems 895
- 33.4 Root Systems 900
- 33.5 Secondary Growth 903

## SUMMARY ILLUSTRATION FOR CHAPTER 33 908

## 34 Transport in Plants 913

- 34.1 Principles of Water and Solute Movement in Plants 914
- 34.2 Uptake and Transport of Water and Solutes by Roots 917
- 34.3 Long-Distance Transport of Water and Minerals in the Xylem 919
- 34.4 Transport of Organic Substances in the Phloem 914

Figure 34.13 Experimental Research Translocation Pressure 925

## SUMMARY ILLUSTRATION FOR CHAPTER 34 928

## 35 Reproduction and Development in Flowering Plants 933

- 35.1 Overview of Flowering Plant Reproduction 934
- 35.2 Flower Structure and Formation of Gametes 936
- 35.3 Pollination, Fertilization, and Germination 940
- 35.4 Asexual Reproduction in Flowering Plants 947

Figure 35.16 Research Method Plant Tissue Culture Protocol 948

35.5 Early Development of Plant Form and Function 949

## SUMMARY ILLUSTRATION FOR CHAPTER 35 950

- 36 Plant Nutrition 955
- 36.1 Plant Nutritional Requirements 956
- Figure 36.2 Research Method Hydroponic Culture 957
- 36.2 Soil 960

36.3 Root Adaptations for Obtaining and Absorbing Nutrients 964

SUMMARY ILLUSTRATION FOR CHAPTER 36 972

37 Plant Signals and Responses to the Environment 977

37.1 Introduction to Plant Hormones 979

Figure 37.3 Experimental Research The Darwins' Experiments on Phototropism 982 Went Demonstrating the Effect of Indoleacetic Acid (IAA) on an Oat Coleoptile 983

- 37.2 Plant Chemical Defences 989
- 37.3 Plant Movements 993
- 37.4 Plant Biological Clocks 997

SUMMARY ILLUSTRATION FOR CHAPTER 37 1002

# UNIT EIGHT SYSTEMS AND PROCESSES: ANIMALS 1007

## 38 Introduction to Animal Organization and Physiology 1007

- 38.1 Organization of the Animal Body 1008
- 38.2 Animal Tissues 1009
- 38.3 Coordination of Tissues in Organs and Organ Systems 1018
- 38.4 Homeostasis 1018

Figure 38.12 Experimental Research Demonstration of the Use of the Bill for Thermoregulation in Birds 1021

## SUMMARY ILLUSTRATION FOR CHAPTER 38 1024

## 39 Animal Nutrition 1029

- 39.1 Nutrients Are Essential Components of Any Diet 1030
- 39.2 Feeding: Obtaining Nutrients 1034
- 39.3 Digestive Processes 1036
- 39.4 Structure and Function of the Mammalian Digestive Tract 1039
- 39.5 Regulation of Digestive Processes 1048

Figure 39.20 Experimental Research Association of Bacterial Populations in the Gut Microbiome with Obesity in Humans 1050

## SUMMARY ILLUSTRATION FOR CHAPTER 39 1052

- 40 Gas Exchange: The Respiratory System 1057
- 40.1 General Principles 1058
- 40.2 Gas Exchange Organs 1061
- 40.3 The Mammalian Respiratory System 1065
- 40.4 Exchange of Gas with Blood 1068
- 40.5 Transport of Gases in Blood 1069

## Figure 40.21 Experimental Research Demonstration of a Molecular Basis for High-Altitude Adaptation in Deer Mice 1073

## SUMMARY ILLUSTRATION FOR CHAPTER 40 1074

- 41 Internal Transport: The Circulatory System 1079
- 41.1 Animal Circulatory Systems: An Introduction 1080
- 41.2 Blood and Its Components 1084
- 41.3 The Heart 1087
- 41.4 Blood Vessels of the Circulatory System 1090
- 41.5 Maintaining Blood Flow and Pressure 1093

NEL

Vasodilatory Signalling Molecule 1094

41.6 The Lymphatic System 1095

## SUMMARY ILLUSTRATION FOR CHAPTER 41 1098

- 42 Regulation of the Internal Environment: Water, Solutes, and Temperature 1103
- 42.1 Introduction to Osmoregulation and Excretion 1104
- 42.2 Osmoregulation and Excretion in Invertebrates 1108
- 42.3 Osmoregulation and Excretion in Non-mammalian Vertebrates 1110
- 42.4 Osmoregulation and Excretion in Mammals 1112

Figure 42.15 Experimental Research ADH-Stimulated Water Reabsorption in the Kidney Collecting Duct 1118

- 42.5 Introduction to Thermoregulation 1120
- 42.6 Ectothermy 1122
- 42.7 Endothermy 1125

## SUMMARY ILLUSTRATION FOR CHAPTER 42 1130

## 43 Control of Animal Processes: Endocrine Control 1135

- 43.1 Hormones and Their Secretion 1136
- 43.2 Mechanisms of Hormone Action 1139

Figure 43.6 Experimental Research Demonstration That Epinephrine Acts by Binding to a Plasma Membrane Receptor 1142

- 43.3 The Hypothalamus and Pituitary 1145
- 43.4 Other Major Endocrine Glands of Vertebrates 1148
- 43.5 Endocrine Systems in Invertebrates 1153

Figure 43.16 Experimental Research Demonstration That Growth and Moulting in Insects Is Hormonally Controlled 1155

## SUMMARY ILLUSTRATION FOR CHAPTER 43 1156

- 44 Animal Reproduction 1161
- 44.1 The Drive to Reproduce 1162
- 44.2 Asexual and Sexual Reproduction 1162

44.4 Sexual Reproduction in Mammals 1171

Figure 44.11 Experimental Research Vocal Cues to Ovulation in Human Females 1172

44.5 Development 1180

## SUMMARY ILLUSTRATION FOR CHAPTER 44 1194

- 45 Control of Animal Processes: Neural Control 1199
- 45.1 The Basis of Information Flow in Nervous Systems: An Overview 1200

Figure 45.13 Experimental Research Demonstration of Chemical Transmission of Nerve Impulses at Synapses 1212

45.2 Sensory Inputs: Reception 1214

Figure 45.25 Experimental Research How Do Sea Urchins Detect Light? 1223

Figure 45.42 Experimental Research Magnetic Sense in Sea Turtles 1234

- 45.3 The Central Nervous System: Integration 1236
- 45.4 The Peripheral Nervous System: Transmission and Response 1247

## SUMMARY ILLUSTRATION FOR CHAPTER 45 1250

- 46 Muscles, Skeletons, and Body Movements 1255
- 46.1 Vertebrate Skeletal Muscle: Structure and Function 1256

Figure 46.5 Experimental Research The Sliding Filament Model of Muscle Contraction 1259

- 46.2 Skeletal Systems 1264
- 46.3 Vertebrate Movement: The Interactions between Muscles and Bones 1267

## SUMMARY ILLUSTRATION FOR CHAPTER 46 1272

Appendix A: Answers to Self-Test Questions A-1 Glossary G-1

Index I-1

Welcome to an exploration of the diversity of life. The main goal of this textbook is to guide you on a journey of discovery about life's diversity across levels ranging from molecules to genes, cells to organs, and species to ecosystems. Along the way, we will explore many questions about the mechanisms underlying diversity as well as the consequences of diversity, for our own species and for others.

## An emphasis on the diversity of life ...

At first glance, the riot of life that animates the biosphere overwhelms our minds. One way to begin to make sense of this diversity is to divide it into manageable sections on the basis of differences. We also consider features found in all life forms to stress similarities as well as differences. We examine how different organisms solve the common problems of finding nutrients, energy, and mates on the third rock from our Sun. What basic evolutionary principles inform the relationships among life forms regardless of their different body plans, habitats, or life histories? Unlike many other first-year biology texts, this book has chapters integrating basic concepts such as the effects of genetic recombination, light, and domestication across the breadth of life from microbes to mistletoe to moose. As you read this book, you will be referred frequently to other chapters for linked information that expands the ideas further.

Evolution provides a powerful conceptual lens for viewing and understanding the roots and history of the diversity of living things. We will demonstrate how knowledge of evolution helps us appreciate the changes we observe in organisms. Whether the focus is the conversion of free-living prokaryotic organisms into mitochondria and chloroplasts or the steps involved in the domestication of rice, selection for particular traits over time can explain the current condition.

Examining how biological systems work is another theme pervading this text and underlying the idea of diversity. We have intentionally tried to include examples that will tax your imagination, from sea slugs that steal chloroplasts for use as solar panels, to the molecular basis of high altitude adaptations in deer mice, to adaptive radiation of viruses. In each situation, we examine how biologists have explored and assessed the inner workings of organisms, from gene regulation to the challenges of digesting cellulose.

Solving problems is another theme that runs throughout the book. Whether the topic is gene therapy to treat a disease in people, increasing crop production, or reducing the incidence of human obesity, both the problem and the solution lie in biology. We will explore large problems facing planet Earth and the social implications that arise from them.

## Emphasizing the big picture ...

Many biology textbooks use the first few chapters to review fundamentals of chemistry and biochemistry as well as information on the scientific method. Instead of focusing on this background information, we have used the first chapter, in particular, to immediately engage students by conveying the excitement that is modern biology. We have put important background information in the centre of the book as a distinct reference section entitled The Chemical and Physical Foundations of Biology. With their purple borders, these pages are distinct and easy to find, and have become affectionately known as The Purple Pages. These pages enable information to be readily identifiable and accessible to students as they move through the textbook rather than being tied to a particular chapter. In this edition, the concepts of atoms, molecules, and macromolecules are connected through the theme of "emergent properties." By considering how the "stuff of life" interrelates as a function of increasing complexity rather than just memorizing the attributes of individual items, students can better grasp why biology works the way it does, rather than be awed by how much information we know about it.

We hope that Canadian students will find the subject of biology as it is presented here accessible and engaging because it is presented in familiar contexts. We have highlighted the work of Canadian scientists, used examples of Canadian species, and referred to Canadian regulations and institutions.

# Focusing on research to help students engage the living world as scientists ...

A primary goal of this book is to evoke and sustain students' curiosity about biology, rather than dulling it with a mountain of disconnected facts. We can help students develop the mental habits of scientists and a fascination with the living world by conveying our passion for biological research. We want to excite students not only with *what biologists know* about the living world but also with *how they know it* and *what they still need to learn*. In doing so, we can encourage some students to accept the challenge and become biologists themselves, posing and answering important new questions through their own innovative research. For students who pursue other careers, we hope that they will leave their introductory—and perhaps only—biology course armed with intellectual skills that will enable them to evaluate future knowledge with a critical eye.

In this book, we introduce students to a biologist's "ways of learning." Research biologists constantly integrate new observations,

knowledge and ideas. To help students engage the world as biologists do, we must not simply introduce them to the current state of knowledge, we must also foster an appreciation of the historical context within which those ideas developed, and identify the future directions that biological research is likely to take.

Because advances in science occur against a background of research, we also give students a feeling for how biologists of the past formulated basic knowledge in the field. By fostering an appreciation of such discoveries, given the information and theories available to scientists in their own time, we can help students understand the successes and limitations of what we consider cutting edge today. This historical perspective also encourages students to view biology as a dynamic intellectual enterprise, not just a collection of facts and generalities to be memorized.

We have endeavoured to make the science of biology come alive by describing how biologists formulate hypotheses and evaluate them using hard-won data; how data sometimes tell only part of a story; and how the results of studies often end up posing more questions than they answer. Our exploration of the Tully Monster in Chapter 27 is a case in point. Since its fossil discovery and description, this mainly soft-bodied animal has been tentatively classified with species in five different groups of animals. Through this example, and throughout Chapter 27, we explore the current recognition that the historical and traditional grouping of animals into protostomes and deuterostomes is more artificial than real.

Although students might prefer simply to learn the "right" answer to a question, they must be encouraged to embrace "the unknown," those gaps in knowledge that create opportunities for further research. An appreciation of what biologists do *not* yet know will draw more students into the field. And by defining *why* scientists do not understand interesting phenomena, we encourage students to think critically about possible solutions and to follow paths dictated by their own curiosity. We hope that this approach will encourage students to make biology a part of their daily lives by having informal discussions and debates about new scientific discoveries.

## Presenting the story line of the research process ...

Science is by its nature a progressive enterprise in which answers to questions open new questions for consideration. In preparing this book, we developed several special features to help students broaden their understanding of the material presented and of the research process itself:

 The chapter openers, titled Why It Matters, are engaging, short vignettes designed to capture students' imaginations and whet their appetites for the topic that the chapter addresses. In many cases, this feature uses current Canadian arrived at a key insight, or how biological research solved a major societal problem, explained a fundamental process, or elucidated a phenomenon. The Why It Matters feature links the insight from the vignette to the contents of the chapter to spark student interest in the topic at hand.

Three types of specially designed research figures provide more detailed information about how biologists formulate specific hypotheses and test them by gathering and interpreting data. Experimental Research figures describe specific studies in which researchers used both experimental and control treatments, either in the laboratory or in the field, to test hypotheses or answer research questions by manipulating the system they studied. Observational Research figures describe specific studies in which biologists have tested hypotheses by comparing systems under varying natural circumstances. Research Method figures provide examples of important techniques, such as light and electron microscopy, the polymerase chain reaction, making a knockout mouse, DNA microarray analysis, plant cell culture, producing monoclonal antibodies, radiometric dating, and cladistic analysis. Each Research Method figure leads a student through the purpose of the technique and protocol, and describes how scientists interpret the data it generates.

# Integrating effective, high-quality visuals into the narrative ...

Today's students are accustomed to receiving ideas and information visually, making the illustrations and photographs in a textbook and the fully integrated online resources critically important. From the first Canadian edition, our illustration program has provided an exceptionally clear supplement to the narrative in a style that is consistent throughout the book. Graphs and anatomical drawings are annotated with interpretive explanations that lead students, step by step, through the major points they convey.

Over subsequent editions, we have continued to enhance the illustration program, focusing on features that reviewers and users of the book identified as the most useful pedagogical tools. In revising the text, we reevaluated each illustration and photograph, and made appropriate changes to improve their utility as teaching tools.

For this most recent edition, we have made some exciting new additions to our illustration program through the creation of *Chapter Roadmaps* and *Summary Illustrations* for every chapter the book. Chapter Roadmaps appear at the beginning of each chapter and provide a visual overview of the chapter contents. Connections between topics across chapters are emphasized to give students a sense of how the content of each chapter fits within the larger context of the book, and biology as a whole. At the end of each chapter, we have created vivid and engaging

teaching heart—of the chapter. These illustrations provide students with a visual overview of the connections between key concepts, and provide a unique touchstone to review and gauge understanding of the chapter contents.

# Organizing chapters around important concepts ...

As authors and university teachers, we understand how easily students can get lost within a chapter. When students request advice about how to read a chapter and learn the material in it, we usually suggest that, after reading each section, they pause and quiz themselves on the material they have just encountered. After completing all the sections in a chapter, they should quiz themselves again, even more rigorously, on the individual sections and, most important, on how the concepts that were developed in the different sections fit together. Accordingly, we have adopted a structure for each chapter to help students review concepts as they learn them.

- The organization within chapters presents material in digestible sections, building on students' knowledge and understanding as they acquire it. Each major section covers one broad topic.
- Study Break questions follow every major section. These
  reading comprehension questions encourage students to
  pause at the end of a section and review what they have
  learned before going on to the next topic within the chapter.
  If a student isn't able to answer a study break question, they
  can immediately revisit the previous section to solidify their
  understanding. We feel that this is a better learning tool than
  directly providing the answers to these questions. If the
  answer does not come easily, then rereading the material
  associated with the answer is as important as seeing the
  answer itself.
- Self-Test Questions are found at the end of each chapter. These chapter review questions are organized according to Bloom's taxonomy into three sections: Recall/Understand, Apply/Analyze, and Create/Evaluate. This structure allows students to review the material in a sequence that moves from the basic knowledge of factual material, to more challenging and sophisticated applications of that knowledge, to novel situations. Answers to the Self-Test Questions are found in an appendix at the back of the book.
- The Chemical and Physical Foundations of Biology, also known as The Purple Pages, keep background information out of the main text, allowing students to focus on the bigger picture.
- Unit 5: The Diversity of Life, also known as The Green Pages, contains readily identifiable chapters that introduce the tremendous variability among living organisms.

## your classroom—online or in class—is now easier than ever ...

The fourth Canadian edition of *Biology: Exploring the Diversity* of *Life* represents a fully integrated package of print and media, providing comprehensive learning tools and flexible delivery options. In preparing this edition, we conducted extensive research to determine how instructors prefer to present online learning opportunities. The result of this research is a new MindTap course organized around the instructors' preferred workflow. Instructors can now select just the content they want to assign, chosen from a comprehensive set of learning materials provided with the course for each chapter. Many types of learning activities are assignable and offer students immediate feedback and automated instructor assessment.

Research also indicates that online content is most effective when it enhances conceptual understanding through the use of relevant applications. In this edition, we have developed new assessable online learning activities that provide students the opportunity to explore and practice biology the way scientists practice biology:

- Interpret the Data exercises have been enhanced by an additional online exercise to further develop student quantitative analysis and mathematical reasoning skills.
- The *Design an Experiment* feature is delivered online as a guided learning activity that takes the student through the process of designing an experiment.
- Conceptual Learning Activities are repeatable in alternate versions to help students learn the material.

The *Instructor Resource Center* provides everything you need for your course in one place. This collection of lecture and class tools is available online for instructors only via www .nelson.com/instructor. There you can access and download PowerPoint presentations, images, the Instructor's Manual, the Test Bank, videos, animations, and more.

To maximize the chances of producing a useful text that draws in students (and instructors), we sought the advice of colleagues who teach biology (members of the MindTap Advisory Board). We also asked students (members of the Student Advisory Boards) for their advice and comments. These groups evaluated the effectiveness of important visuals in the textbook, evaluated draft chapters, and provided valuable feedback on the MindTap, but any mistakes are ours.

In summary, we have applied our collective experience as teachers, researchers, and writers to create a readable and understandable foundation for students who may choose to enrol in more advanced biology courses in the future. Where appropriate, we provide straightforward explanations of fundamental concepts from the evolutionary perspective that binds together all the biological sciences. Recognizing that students in an introductory biology course face a potentially daunting quantity of ideas and information, we strive to provide an appropriate