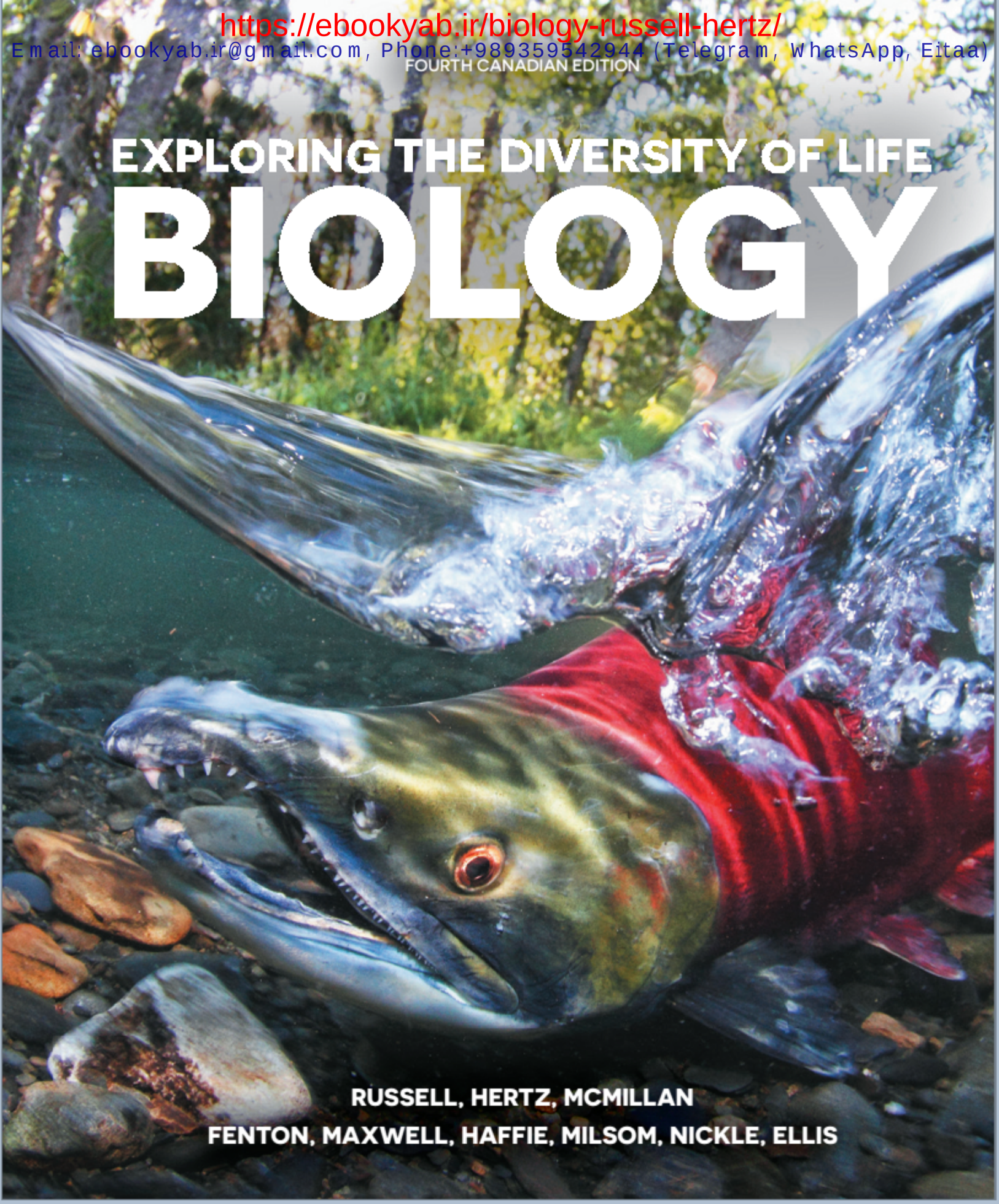
FOURTH CANADIAN EDITION

EXPLORING THE DIVERSITY OF LIFE

BIOLOGY



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BIOLOGY

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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

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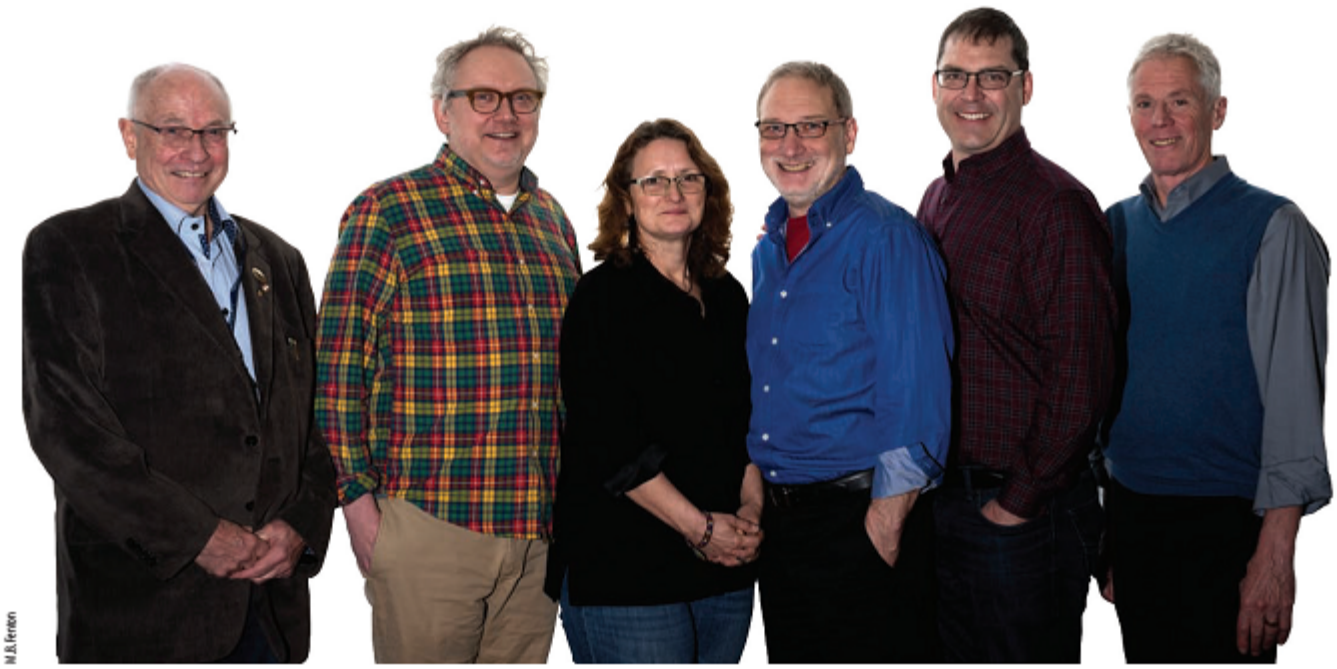
For, and because of,
our generations of students.



About the Canadian Authors


M. B. Fenton

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.


Alan Wilson

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

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.


Bruce Hertzel

Bill Milsom (Ph.D., University of British Columbia) is 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 of biodiversity and the physiological costs of habitat selection. 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.


Penny Nickle

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*[3]). 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.


Andy Catron

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.

About the U.S. Authors

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

Jacob Blind

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 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.

Courtesy of Beverly McMillan

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.

Brief Contents

Contents

Preface

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,

hypotheses, questions, experiments, and insights with existing 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 examples and tells the story of how a researcher or researchers 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

Summary Illustrations that depict the core concepts—and 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.

Effectively introducing digital solutions into 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