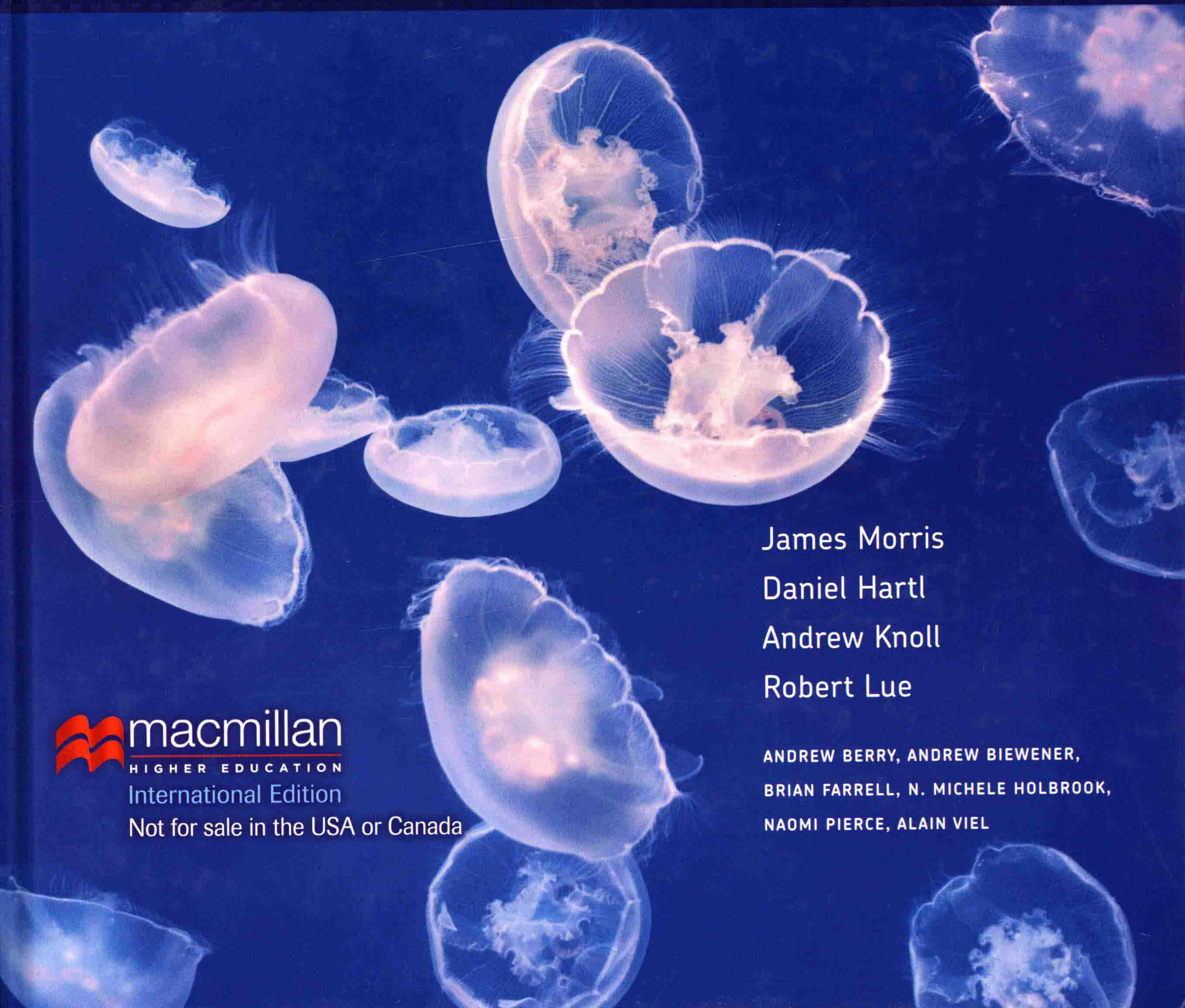
BIOLOGY
HOW LIFE WORKS



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To all who are curious
about life and how it works.

ABOUT THE AUTHORS

James R. Morris is Associate Professor in the Biology Department at Brandeis University. He teaches introductory biology, as well as a wide variety of courses for majors and non-majors in evolution, genetics, genomics, and anatomy. In addition, he teaches a first-year seminar focusing on Darwin's *On the Origin of Species*. He is the recipient of numerous teaching awards. His research focuses on the rapidly growing field of epigenetics, using the fruit fly *Drosophila melanogaster* as a model organism. He currently pursues this research with undergraduates in order to give them the opportunity to do genuine, laboratory-based research early in their scientific careers. Dr. Morris received a PhD in genetics from Harvard University and an MD from Harvard Medical School. He was a Junior Fellow in the Society of Fellows at Harvard University, has given talks to the public on current science at the Museum of Science in Boston, and works on promoting public understanding of personal genetics and genomics.

Daniel L. Hartl is Higgins Professor of Biology in the Department of Organismic and Evolutionary Biology at Harvard University. He has taught highly popular courses in genetics and evolution at both the introductory and advanced levels. His lab studies molecular evolutionary genetics and population genetics and genomics. Dr. Hartl is the recipient of the Samuel Weiner Outstanding Scholar Award and the Medal of the Stazione Zoologica Anton Dohrn, Naples. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. He has served as President of the Genetics Society of America and President of the Society for Molecular Biology and Evolution. Dr. Hartl's PhD was awarded by the University of Wisconsin, and he did postdoctoral studies at the University of California, Berkeley. Before joining the Harvard faculty, he served on the faculties of the University of Minnesota, Purdue University, and Washington University Medical School. In addition to publishing more than 350 scientific articles, Dr. Hartl has authored or coauthored 30 books.

Andrew H. Knoll is Fisher Professor of Natural History in the Department of Organismic and Evolutionary Biology at Harvard University. He is also Professor of Earth and Planetary Sciences. Dr. Knoll teaches introductory courses in both departments. His research focuses on the early evolution of life, Precambrian environmental history, and the interconnections between the two. He has also worked extensively on the early evolution of animals, mass extinction, and plant evolution. He currently serves on the science team for NASA's mission to Mars. Dr. Knoll received the Phi Beta Kappa Book Award in Science for *Life on a Young Planet*. Other honors include the Paleontological Society Medal and Wollaston Medal of the Geological Society, London. He is a member of the National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society. He received his PhD from Harvard University and then taught at Oberlin College before returning to Harvard.

Robert A. Lue is Professor in the Department of Molecular and Cellular Biology and Director of Life Science Education at Harvard University. He regularly teaches courses in Harvard's first-year Life Sciences program and upper-level courses in cell biology. He has a long-standing commitment to interdisciplinary teaching and research, and chaired the faculty committee that developed an integrated science course to serve science majors and premedical students. Dr. Lue has also developed award-winning multimedia, including the animation "The Inner Life of the Cell." He has coauthored undergraduate biology textbooks and chaired education conferences on college biology for the National Academies and the National Science Foundation and on diversity in science for the Howard Hughes Medical Institute and the National Institutes of Health. He also founded and directs a Harvard Life Sciences outreach program that serves over 50 high schools. He received his PhD from Harvard University.

Andrew Berry is Lecturer in the Department of Organismic and Evolutionary Biology and an undergraduate advisor in the Life Sciences at Harvard University. He teaches courses in Harvard's first-year Life Sciences program, as well as courses on evolution and Darwin. His research interests are in evolutionary biology and the history of science. He has coauthored two books: *Infinite Tropics*, a collection of the writings of Alfred Russel Wallace, and *DNA: The Secret of Life*, which is part history, part exploration of the controversies swirling around DNA-based technology.

Andrew A. Biewener is Charles P. Lyman Professor of Biology in the Department of Organismic and Evolutionary Biology at Harvard University and Director of the Concord Field Station. He teaches both introductory and advanced courses in anatomy, physiology, and biomechanics. His research focuses on the comparative biomechanics and neuromuscular control of mammalian and avian locomotion, with relevance to biorobotics. He is currently Deputy Editor-in-Chief for the *Journal of Experimental Biology*. He also served as President of the American Society of Biomechanics.

Brian D. Farrell is Professor of Biology in the Department of Organismic and Evolutionary Biology at Harvard University and Curator of Entomology in the Museum of Comparative Zoology. He has collaborated with Los Niños de Leonardo y Meredith in the Dominican Republic to teach children about native insects, and participates in an All Taxa Biodiversity Inventory of the Boston Harbor Islands National Recreation Area. His research focuses on the interplay of adaptation and historical contingency in species diversification, particularly of beetles. In 2011–2012, Dr. Farrell was a Fulbright Scholar to the Universidad Autonoma de Santo Domingo.

N. Michele Holbrook is Charles Bullard Professor of Forestry in the Department of Organismic and Evolutionary Biology at Harvard University. She teaches an introductory course on biodiversity as well as advanced courses in plant biology. She studies the physics and physiology of vascular transport in plants with the goal of understanding how constraints on the movement of water and solutes between soil and leaves influences ecological and evolutionary processes.

Naomi E. Pierce is Hessel Professor of Biology in the Department of Organismic and Evolutionary Biology at Harvard University and Curator of Lepidoptera in the Museum of Comparative Zoology. She studies and teaches animal behavior and behavioral ecology. Her lab focuses on the ecology of species interactions, such as insect–host plant associations, and on the life-history evolution and systematics of Lepidoptera. She has also been involved in reconstructing the evolutionary tree of life of insects such as ants, bees, and butterflies.

Alain Viel is Director of Undergraduate Research and Senior Lecturer in the Department of Molecular and Cellular Biology at Harvard University. He teaches research-based courses as well as courses in molecular biology and biochemistry. He is a founding member of BioVisions, a collaboration between scientists, teaching faculty, students, and multimedia professionals that focuses on science visualization. Dr. Viel worked with his colleague and *Biology: How Life Works* coauthor Robert Lue on the animation "The Inner Life of the Cell."

Biology: How Life Works Assessment Authors

Melissa Michael, Lead Assessment Author, is Director for Core Curriculum and Assistant Director for Undergraduate Instruction for the School of Molecular and Cellular Biology at the University of Illinois at Urbana-Champaign. A cell biologist, she primarily focuses on the continuing development of the School's undergraduate curricula. She is currently engaged in several projects aimed at improving instruction and assessment at the course and program levels. She continues to work in several different arenas to improve undergraduate biology education.

Mark Hens is Associate Professor of Biology at the University of North Carolina at Greensboro. He has taught introductory biology at this institution since 1996. He is the director of his department's Introductory Biology Program and is chair of the university's General Education Council. In these administrative capacities, he leads efforts on his campus to establish learning objectives and develop assessment tools. Dr. Hens is a National Academies Education Mentor at the National Academies/HHMI Summer Institute for Undergraduate Education in Biology. He also serves on the advisory board of an NSF-funded project focused on the assessment of student learning in college science curricula.

John Merrill is Director of the Biological Sciences Program in the College of Natural Science at Michigan State University. This program administers the core biology course sequence required for all science majors. In recent years, Dr. Merrill has focused his research on teaching and learning. With the support of several NSF grants, he is exploring innovative classroom interventions coupled to enhanced assessment. A particularly active area is the use of computers to analyze student's written responses to conceptual assessment questions, with the goal of making it easier to use open-response questions in large-enrollment classes.

Randall Phillis is Associate Professor of Biology at the University of Massachusetts Amherst. He has taught in the majors introductory biology course at this institution for 19 years and is a National Academies Education Mentor in the Life Sciences. With help from the PEW Center for Academic Transformation (1999), he has been instrumental in transforming the introductory biology course to an active learning format that makes use of classroom communication systems. He also participates in an NSF-funded project to design model-based reasoning assessment tools for use in class and on exams. These tools are being designed to develop and evaluate student scientific reasoning skills, with a focus on topics in introductory biology.

Debra Pires is an Academic Administrator at the University of California, Los Angeles. She teaches the introductory courses in the Life Sciences Core Curriculum. Her research focuses on creating assessment tools to evaluate how well students understand concepts taught in the introductory courses and how well they retain those concepts during their time at UCLA. Student Learning Outcome (SLO)-centered assessments have become a major component of the introductory curriculum, and workshops with faculty in two departments have begun to help instructors develop rubrics and assessment strategies that are aligned with the goals of the long-term study.

VISION AND STORY OF

Dear Students and Instructors,

We wrote this book in recognition of recent and exciting changes in biology, education, and technology. There was a time when introductory biology could cover all of biology over the course of a single year. This is no longer possible. The amount of scientific information has grown exponentially, necessitating that we, as teachers, rethink the role of introductory biology and the resources that support it. One goal remains paramount: to help students think like biologists. To think like a biologist means understanding key concepts that span all of biology. It means being able to communicate in the shared language of biologists. It means recognizing the powerful ability of evolution to explain both the unity and diversity of life. It means thinking about how biological research can help solve some of the world's most pressing issues, from cancer to infectious diseases to biodiversity loss to climate change.

We have also noticed a change in the way biological problems are approached. We now have a "parts list" of genes and proteins for how life works, and many scientists today are focused on how the parts work together. As a result, we can no longer divide information into discrete topics. To prepare students for science as it is currently practiced, we must integrate concepts from different areas of biology as well as from other scientific disciplines.

What is particularly exciting for us as teachers is that the remarkable changes in the science of biology are paralleled by a new appreciation for and understanding of how students learn. There is now good evidence that teaching students only by lecturing does not lead to mastery of core concepts. Lecturing alone does not help develop the scientific skills and habits of mind that students need to become successful scientists and health-care workers or thoughtful, scientifically informed citizens. Students learn most effectively when they are actively involved in their learning and construct their own knowledge through a combination of lectures, problem solving, hands-on experiences, and collaborative work.

At the same time, technology is transforming how and where students access information. The Internet provides all kinds of information at a click. There is no need for a modern textbook to be a reference book. What, then, is the role of a textbook? A textbook needs to be selective, help students see connections between seemingly disparate topics, and make the material engaging and relevant. Technology is also making possible new and unprecedented ways to visualize biological processes and provide interactive ways for students to learn.

To support 21st-century student learning and instructor teaching, we feel that it is time to rethink what takes place both in and out of the introductory biology classroom and to reimagine the resources that can best support these efforts. *Biology: How Life Works* provides an integrated set of resources to engage students, encourage critical thinking, help students make connections, and provide a framework for further studies.

Sincerely,
The *Biology: How Life Works* author team

Rethinking Biology

For the *Biology: How Life Works* team, it has been an exciting experience to reimagine what a resource for today's students should look like. We began with the question, "What do we want students to understand and apply at the end of the course?" Once we decided where we wanted students to end up, we started asking other questions: What content should be covered? How should it be organized? How should it be delivered—in the narrative, a figure, an animation? What questions should we ask students to gauge their understanding? What questions should we ask to help students work toward that understanding? Through this process of questioning and answering, one point became clear—we'd have to start from scratch and build *Biology: How Life Works* from the ground up.

Rethinking biology means rethinking the text, visual program, and assessment.

Rethinking biology required rethinking the way a textbook is created. Ordinarily, textbooks are developed by first writing chapters, then making decisions about art and images, and finally, once the book is complete, assembling a test bank and ancillary media. This process dramatically limits integration across resources and reduces art, media, and assessments to supplements rather than essential resources for student learning.

Biology: How Life Works is the first project to develop three pillars of learning—the text, visual program, and assessment—at the same time. These three pillars are all tied to the same set of core concepts, share a common language, and use the same visual palette. In this way, the visual program and assessments are integral parts of student learning, rather than accessories to the text. In addition, every concept is conveyed and explored in multiple ways, allowing for authentic learning.

I think the best selling point is that the text focuses on helping students make connections between the subfields of biology.
CINDEE GIFFEN, INSTRUCTOR
UNIVERSITY OF WISCONSIN, MADISON

I like its simplicity and focus on key concepts using relevant examples. Linkage to previous chapters was one of the strongest parts.
DAVID HICKS, INSTRUCTOR
THE UNIVERSITY OF TEXAS AT BROWNSVILLE

I really like the streamlined approach and emphasis on ideas and concepts rather than details and facts.
SCOTT SOLOMON, INSTRUCTOR
RICE UNIVERSITY

I like the evolution emphasis throughout. If evolution really is the central organizing principle in biology, it's about time somebody wrote an introductory textbook that reflects that.
DAVID LAMPE, INSTRUCTOR
DUQUESNE UNIVERSITY

I think it is more readable than the text we currently use and it does a better job of integrating the theme of evolution.
KATHRYN CRAVEN, INSTRUCTOR
ARMSTRONG ATLANTIC UNIVERSITY

Rethinking biology means rethinking THE TEXT

Biology: How Life Works includes a text that is uniquely *integrated*, *selective*, and *thematic*.

INTEGRATED

Textbooks commonly present biology as a series of minimally related chapters. This style of presentation lends itself to memorization and offers students little guidance on how concepts connect to one another and to the bigger picture. *Biology: How Life Works* moves away from this model and toward an integrated approach. Across the book, we present chemistry in context, and cover structure and function together. We introduce the flow of information in a cell where it makes the most conceptual sense and use cases as a framework for connecting and assimilating information.

SELECTIVE

With the ever-increasing scope of biology, it is unrealistic to expect the majors course or a textbook to cover everything. From the start, we envisioned *Biology: How Life Works* not as a reference book for all of biology, but as a resource focused on foundational concepts, terms, and experiments. We explain fundamental topics carefully, with an appropriate amount of supporting detail. This allows students to more easily identify, understand, and apply critical concepts. In this way, students will leave an introductory biology class with a framework on which to build.

THEMATIC

We wrote *Biology: How Life Works* with six themes in mind. Deciding on these themes in advance helped us make decisions about which concepts to include and how to organize them. Introduced in Chapter 1 and revisited throughout the text, the themes provide a framework that helps students see biology as a set of connected concepts. In particular, we emphasize the theme of evolution for its ability to explain and predict so many patterns in biology.

1. We learn how life works by applying the scientific method, which involves making observations, generating hypotheses, and testing hypotheses through experiment and observation.
2. Life works according to fundamental principles of chemistry and physics. All organisms share a limited number of molecules and chemical processes.
3. All of the chemical and physical functions of life are packaged within cells. Multicellular organisms function by the differentiation and coordinated operation of many cells.
4. Both the features that organisms share and those that set them apart are explained by evolution. Variation exists within as well as between species.
5. Organisms interact in nature, with basic features of anatomy, physiology, and behavior shaping the ecological systems that sustain life.
6. Humans have emerged as major agents in ecology and evolution. Our future welfare depends, in part, on improving our knowledge of how life works.

I think the figures are much simpler for beginning students to understand. I found all of the figures in my chapter to be clear, concise, and distilled into the most relevant facts necessary to illustrate the concepts.
DALE CASAMATTA, INSTRUCTOR
UNIVERSITY OF NORTH FLORIDA

The figures in this chapter [Chapter 22: Species and Speciation] are particularly good. These are not the only great figures, but they are among my favorites for how they demonstrate a concept so easily that might otherwise require a couple of paragraphs of text.
MATT BREWER, INSTRUCTOR
GEORGIA STATE UNIVERSITY

My initial reaction was "Wow." It [animation on gene expression] helped me visualise the spatial relationships associated with information flow at the cellular level, and I think it is thus likely to really help undergraduates.
DAVE KUBIEN, INSTRUCTOR
UNIVERSITY OF NEW BRUNSWICK

Rethinking biology means rethinking THE VISUAL PROGRAM

The *Biology: How Life Works* visual program—all art and visual media—is an *integrated, engaging, visual framework* for understanding and connecting concepts.

INTEGRATED

Just as we decided on a consistent vocabulary to explain concepts and processes, we also created a consistent "visual language." This means that across *Biology: How Life Works*—whether students are looking at a figure in the book, watching an animation, or interacting with a simulation—they see a consistent use of color, shapes, and design. Having a coherent, integrated visual program allows students to recognize concepts they have already encountered, and assimilate new information.

ENGAGING

We have a shared goal with instructors—we want students to *want* to learn more. Cognitive science tells us visualization is tremendously effective at triggering student interest and passion. With that in mind, the *Biology: How Life Works* team committed to designing and developing a visual program with the same attention and care that goes into text development. Every image—still and in motion—engages students by being vibrant, clear, and approachable. The result is a visual environment that pulls students in, deepens their interest, and helps them see a world of biological processes.

VISUAL FRAMEWORK

Scientists often build a contextual picture, or visual framework, in their mind upon which they hang facts and connect ideas. To help students think like biologists, our visual program deliberately provides this type of framework. Individual figures present foundational concepts; Visual Synthesis figures tie together multiple concepts across multiple chapters; animations bring these figures to life, allowing students to explore concepts in space and time; and simulations have students interact with the concepts. Collectively, this visual framework gives students a way to contextualize information—to move seamlessly back and forth between the big picture and the details, from the basic to the complex.

The pre-class questions are basic and yet not simple repeat-from-reading, and the other questions fit comfortably at the level where I think they'll challenge my students but not be so difficult they're unreachable for them. I particularly like that many of these questions involve interpreting data, or analyzing a case story.
ANNE CASPER
EASTERN MICHIGAN UNIVERSITY

These questions are great in that they really require a greater depth of understanding and ability to apply concepts than I've seen in any other assessment packages. There's a clear connection between the pedagogical approach of the textbook and the assessment materials.
SONJA PYOTT, INSTRUCTOR
UNIVERSITY OF NORTH CAROLINA AT WILMINGTON

The questions in these assessments seem to be superior, since they require higher-order thinking and application of knowledge, rather than just simple factual recall.
PEGGY ROLFSEN, INSTRUCTOR
CINCINNATI STATE TECHNICAL AND COMMUNITY COLLEGE

There are more suggestions about how to use various types of assessments—my current text gives examples of questions but it is left to me to imagine how I might use them.
LISA ELFRING
UNIVERSITY OF ARIZONA

Rethinking biology means rethinking ASSESSMENT

Biology: How Life Works represents a groundbreaking departure from traditional assessment materials. Written by leaders in science education in collaboration with the authors, our assessments are fully ***integrated*** with the text and visual program, span the *full range of Bloom's Taxonomy,* and are properly ***aligned.***

INTEGRATED

If assessment is important, it cannot be ancillary—it must be integral to the learning process. Each time an instructor asks a student to engage with *Biology: How Life Works*—whether it is reading a chapter, watching an animation, or working through an experiment—the opportunity to assess that experience exists. This unprecedented level of integration results from developing assessments alongside the text and visual program. This parallel development also allows for consistency of language and focus, helping students connect what they have read with the questions they are being asked to answer.

RANGE

For the first time, instructors in majors biology have access to a set of thoughtfully developed, peer-reviewed formative and summative assessments. Most test banks consist entirely of low-order, recall questions. Consequently, instructors wanting to teach and test at a range of levels are left with the time-consuming task of creating their own higher-order questions. The *Biology: How Life Works* assessment team has done the "heavy lifting" of question writing for instructors—providing assessments that span everything from recall to synthesis. They are designed to be used in a range of settings (pre-class, in-class, post-class, and exam) and come in a variety of formats (multiple choice, multiple true/false, free response). In addition to questions, our assessments include in-class activities and interactive, online exercises.

ALIGNED

Traditionally, assessment questions are provided as test banks, organized by chapter but not as a series designed to work together. We believe questions aren't just for testing—they are for teaching. To help instructors assess students in more meaningful ways, we wrote and organized sets of questions we call *progressions.* Progressions include formative and summative assessment—reading comprehension questions, in-class activities, post-class assignments, and exam questions—all properly aligned with the text's core concepts. Used in sequence, questions within a progression provide a connected learning path for students and a suggested teaching path for instructors.

I think it's time for an innovative approach to a biology text for majors. Your team of authors has the ideal combination of research and teaching experience to be successful in developing a superior text that reflects the contemporary biological sciences.
ERIK SKULLY
TOWSON UNIVERSITY

It has a really fresh narrative voice. . . . It kept the details to a minimum, but presented the information clearly enough that I think students will get the big picture without getting bogged down in the details. Where details were given, they were mostly based on exciting, new findings in the field.
LAURA BERMINGHAM
UNIVERSITY OF VERMONT

I've reviewed several chapters now, and I like the writing style. It seems more engaging and easy to read, and feels less like reading an encyclopedia than other textbooks do.
MARYJO WITZ
MONROE COMMUNITY COLLEGE

AUTHORING *BIOLOGY: HOW LIFE WORKS*

Biology: How Life Works is authored by a team of nationally recognized scientists and educators.

James Morris, Lead Author, Brandeis University
Daniel Hartl, Lead Author, Harvard University
Andrew Knoll, Lead Author, Harvard University
Robert Lue, Lead Author and Visual Program Director, Harvard University
Andrew Berry, Author, Harvard University
Andrew Biewener, Author, Harvard University
Brian Farrell, Author, Harvard University
N. Michele Holbrook, Author, Harvard University
Naomi Pierce, Author, Harvard University
Alain Viel, Author, Harvard University

Melissa Michael, Lead Assessment Author, University of Illinois at Urbana-Champaign
Mark Hens, Assessment Author, University of North Carolina at Greensboro
John Merrill, Assessment Author, Michigan State University
Randall Phillis, Assessment Author, University of Massachusetts Amherst
Debra Pires, Assessment Author, University of California, Los Angeles

The mission of *Biology: How Life Works* is not to cover all of biology, but to provide a proper introduction. This selective approach requires a large team of educators who are experts in their respective fields. Because the authors possess an intimate knowledge of their fields, they were able to step back and consider where their fields have been, what questions are currently being asked, and where they are heading. It is only with a *collective* perspective that *Biology: How Life Works* is able to present contemporary biology in a complete but selective manner.

The multi-author approach was also necessary for the amount of writing, design, development, and collaboration this project required. With the text, visual program, and assessments all being developed in parallel, *Biology: How Life Works* needed more than one author. Additionally, the level of integration, creativity, and new ideas present in the three pillars of *Biology: How Life Works* was largely achieved by having a community of authors who were able to dialogue, discuss, and debate.

At the same time, *Biology: How Life Works* has a single voice. This is possible because every chapter, image, animation, and assessment flowed through one author, James Morris. In this way, it benefits from multi-author expertise while telling a single, cohesive story.

In sum, the size of the author team is purposeful and directly supports the goals of the project.

KEY FEATURES SUPPORTING THE VISION

TOPIC COVERAGE AND ORDER:

The goal of a single narrative of biology is supported by the Table of Contents. a select number of important and purposeful changes. Below is an annotated table of

TABLE OF CONTENTS | BIOLOGY: HOW LIFE WORKS

PART 1: FROM CELLS TO ORGANISMS

Chapter 1 introduces evolution as a major theme of the book before discussing microevolution in Chapter 4 as a foundation for later discussions of conservation of metabolic pathways and enzyme structure (Chapters 6–8) and genetic and phenotypic variation (Chapters 14 and 15). After the chapters on the mechanisms of evolution (Chapters 21–24), we discuss diversity of all organisms in terms of adaptations and comparative features, culminating in ecology as the ultimate illustration of evolution in action.

The first set of chapters emphasizes three key aspects of a cell—information, homeostasis, and energy. Chemistry is taught in the context of biological processes, highlighting the principle that structure determines function.

I found [Chapter 2: The Molecules of Life] quite readable and it makes the chemistry seem much more relevant to organisms from the beginning.

UDO SAVALLI, INSTRUCTOR
ARIZONA STATE UNIVERSITY WEST

The genetics chapters start with genomes, move to mutation and genetic variation, and then consider inheritance to provide a modern, molecular look at genetic variation and how traits are transmitted.

The book's chapters and sections are arranged in a familiar way to be used in a range of introductory biology courses, with contents, highlighting these changes and the reasons behind them.

PART 2: FROM ORGANISMS TO THE ENVIRONMENT

[Chapter 25: Cycling Carbon] **does a great job connecting the "halves"; providing examples in the text and asking questions along the way forces the student to give some thought to the topic. . . . Well done.**
Stephen Trumble
Baylor University

We present the carbon cycle as a bridge between the molecular and organismal parts of the book, integrating ecology and diversity.

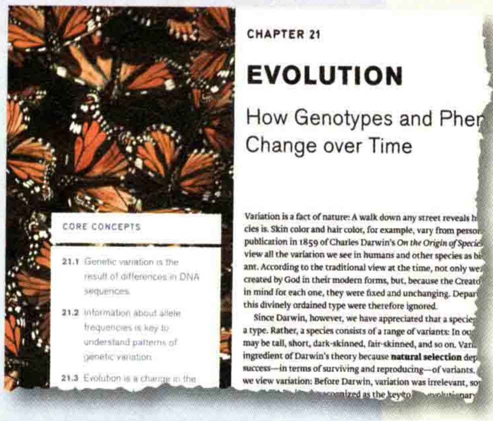
The plant chapters combine content in novel ways to better integrate content and provide context for biological processes, such as plant reproduction with the timing of reproductive events.

Diversity follows physiology in order to provide a basis for understanding the groupings of organisms.

▪ *Biology: How Life Works* includes chapters that don't traditionally appear in introductory biology texts, one in almost every major subject area. These novel chapters represent shifts toward a more modern conception of certain topics in biology:

- The basis of complex traits (Chapter 18)
- Human evolution (Chapter 24)
- Cycling carbon (Chapter 25)
- Multicellularity (Chapter 28)
- Plant defenses (Chapter 32)
- Human impact on the environment (Chapter 48)

CONNECTED LEARNING PATH



CHAPTER 21

EVOLUTION

How Genotypes and Phen[otypes] Change over Time

CORE CONCEPTS

21.1 Genetic variation is the result of differences in DNA sequences.

21.2 Information about allele frequencies is key to understand patterns of genetic variation.

21.3 Evolution is a change in the

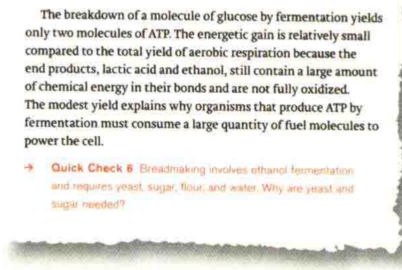
Variation is a fact of nature: A walk down any street reveals h... cies is. Skin color and hair color, for example, vary from perso... publication in 1859 of Charles Darwin's *On the Origin of Specie[s]* ... view all the variation we see in humans and other species as bi... ant. According to the traditional view at the time, not only we... created by God in their modern forms, but, because the Creato... in mind for each one, they were fixed and unchanging. Depar... this divinely ordained type were therefore ignored.

Since Darwin, however, we have appreciated that a specie... a type. Rather, a species consists of a range of variants: In ou... may be tall, short, dark-skinned, fair-skinned, and so on. Vari... ingredient of Darwin's theory because **natural selection** dep... success—in terms of surviving and reproducing—of variants. ... we view variation: Before Darwin, variation was irrelevant, so...

The authors of *Biology: How Life Works* rethought the standard pedagogical tools like chapter summaries and end-of-chapter questions. Each element purposefully relates to the same set of core concepts and functions as a connected learning path for students.

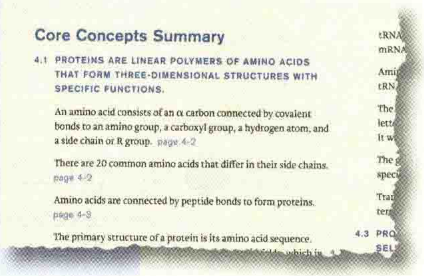
Core Concepts listed at the beginning of each chapter map to the chapter's numbered sections and give students a preview of what ideas they should know by the time they finish reading. We built each chapter around core concepts in order to focus on the most important and overarching ideas in any one topic.

Throughout the chapter, Quick Checks ask students to pause and make sure they're ready to move on to the next idea. These brief questions pointedly ask the student to demonstrate a full understanding of a tough topic before reading on.



The breakdown of a molecule of glucose by fermentation yields only two molecules of ATP. The energetic gain is relatively small compared to the total yield of aerobic respiration because the end products, lactic acid and ethanol, still contain a large amount of chemical energy in their bonds and are not fully oxidized. The modest yield explains why organisms that produce ATP by fermentation must consume a large quantity of fuel molecules to power the cell.

→ **Quick Check 6** Breadmaking involves ethanol fermentation and requires yeast, sugar, flour, and water. Why are yeast and sugar needed?



Core Concepts Summary

4.1 PROTEINS ARE LINEAR POLYMERS OF AMINO ACIDS THAT FORM THREE-DIMENSIONAL STRUCTURES WITH SPECIFIC FUNCTIONS.

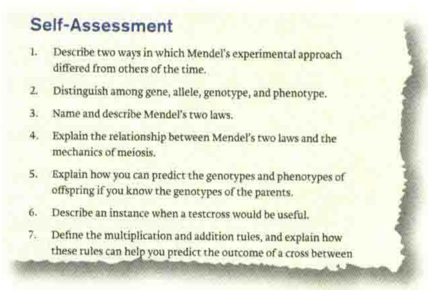
An amino acid consists of an α carbon connected by covalent bonds to an amino group, a carboxyl group, a hydrogen atom, and a side chain or R group. page 4-2

There are 20 common amino acids that differ in their side chains. page 4-2

Amino acids are connected by peptide bonds to form proteins. page 4-3

The primary structure of a protein is its amino acid sequence.

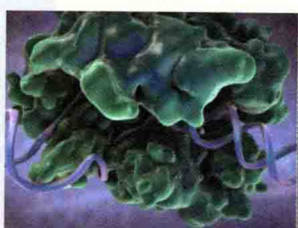
Students revisit the core concepts in the Core Concepts Summary. Here, they can remind themselves of the big-picture ideas from the beginning of the chapter and see them in the context of key supporting ideas.



Self-Assessment

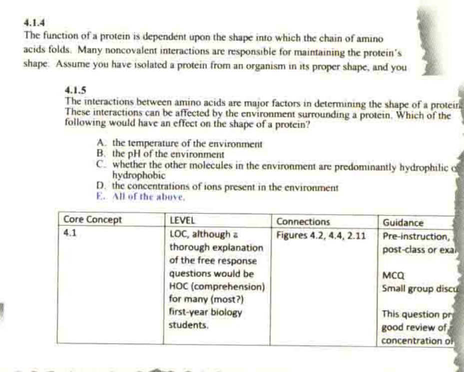
1. Describe two ways in which Mendel's experimental approach differed from others of the time.
2. Distinguish among gene, allele, genotype, and phenotype.
3. Name and describe Mendel's two laws.
4. Explain the relationship between Mendel's two laws and the mechanics of meiosis.
5. Explain how you can predict the genotypes and phenotypes of offspring if you know the genotypes of the parents.
6. Describe an instance when a testcross would be useful.
7. Define the multiplication and addition rules, and explain how these rules can help you predict the outcome of a cross between

Students test their understanding of core concepts with Self-Assessments. These assessments, along with the online answer guides, allow students to see for themselves whether or not they have understood the major ideas of the chapter.



Learning doesn't end when the printed chapter ends. A wealth of media organized by core concept, including dynamic, zoomable Visual Synthesis figures, animations, and simulations, reinforce what students have read. Assessments give students opportunities to apply what they have learned and hone problem-solving skills.

Instructors can use and assign material from a set of questions we call progressions. Progressions offer questions designed as a sequence to use before, during, and after lecture. Progressions help instructors align the questions they ask on exams to the in-class activities and homework questions they have students engage in before an exam.



4.1.4
The function of a protein is dependent upon the shape into which the chain of amino acids folds. Many noncovalent interactions are responsible for maintaining the protein's shape. Assume you have isolated a protein from an organism in its proper shape, and you

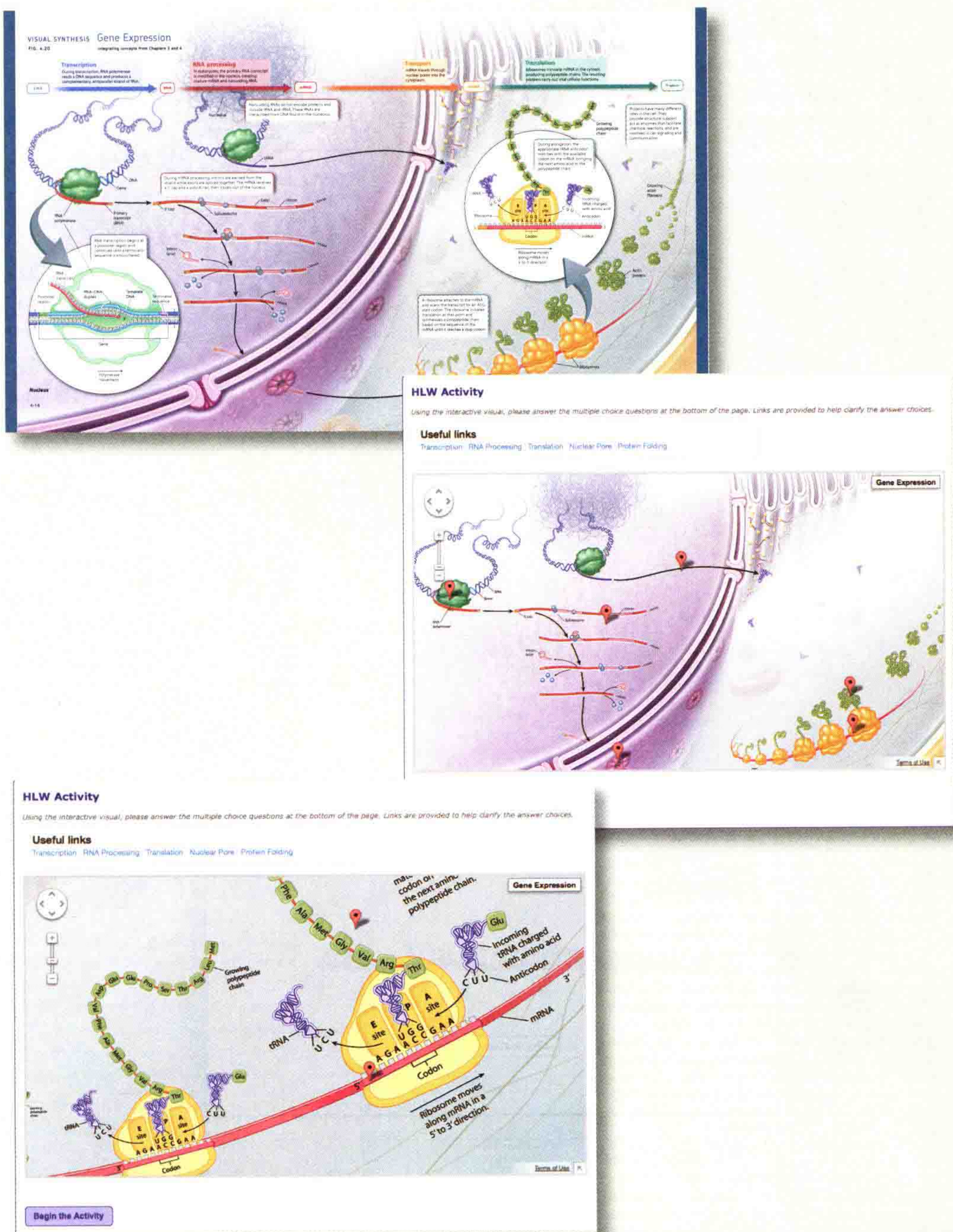
4.1.5
The interactions between amino acids are major factors in determining the shape of a protein. These interactions can be affected by the environment surrounding a protein. Which of the following would have an effect on the shape of a protein?

A. the temperature of the environment
B. the pH of the environment
C. whether the other molecules in the environment are predominantly hydrophilic or hydrophobic
D. the concentrations of ions present in the environment
E. All of the above.

Core Concept	LEVEL	Connections	Guidance
4.1	LOC, although a thorough explanation of the free response questions would be HOC (comprehension) for many (most?) first-year biology students.	Figures 4.2, 4.4, 2.11	Pre-instruction, post-class or exa... MCQ Small group discu... This question pr... good review of... concentration o...

VISUAL SYNTHESIS FIGURES

Just as we integrate topics in biology to create a single narrative, it's our goal to extend integration to the media by creating a seamless path from the book to all online materials. Visual Synthesis figures represent one way that we integrate the text and media. In the book, a Visual Synthesis figure is a two-page spread and serves as a visual summary integrating concepts across multiple chapters. These figures help students look beyond chapter divisions and see how concepts combine to tell a single story. Students continue their exploration online, where they can interact with a dynamic Visual Synthesis figure. Zooming in and out, students can explore both the big picture and the details, building a framework for how concepts connect and relate. The Visual Synthesis figure also functions as a launch pad to other resources, like animations, simulations, and assessment questions.



The course I teach strives to integrate concepts across multiple levels of biological complexity and Visual Synthesis would help with this goal.
Bretton Kent, Instructor
University of Maryland

Visual Synthesis does a great job of summarizing the content of [Chapter 42: Reproduction] in terms of human development. It appears to be very comprehensive including the concepts of fertilization, cleavage (including both maternal and fetal transcription controls) all the way through cell differentiation and tissue development.
Cynthia Littlejohn, Instructor
University of Southern Mississippi

The zoomable Visual Synthesis image is an incredibly powerful visual aid for students, allowing instructors to bridge the gap between the details and the larger concept.
Robert Maxwell, Instructor
Georgia State University

The zoomable digital media is an excellent tool for students and instructors! The interactive capabilities and ability to view content on different levels of complexity are unlike anything I have seen from other texts.
Jeanelle Morgan, Instructor
Gainesville State College

I would like to incorporate more animations, virtual labs, and real-life scenarios relating to the concepts we are learning in lecture. It is incredibly helpful when these resources are created by the textbook publisher, so they correspond directly to the material I am covering.

ASHLEY SPRING
BREVARD COMMUNITY COLLEGE

Students have trouble visualizing cellular activities, so we constantly look for tools to enhance their understanding.

MARGARET OTT
TYLER JUNIOR COLLEGE

ANIMATIONS AND SIMULATIONS

Biological processes are not static—they are dynamic, always in motion. We use animations as an engaging and revealing way to bring biological processes to life, place them in context, and give students an intuitive sense of how these processes work.

Some concepts are best learned by doing, rather than by reading or watching. *Biology: How Life Works* simulations allow students to explore biological processes directly and problem solve by doing. Each simulation asks students to work within or break a system, and assessment questions lead students through the system so they can work through a core concept.

The animations and simulations are available independently but are also integrated into the online, zoomable *Visual Synthesis* figures. In exploring the *Visual Synthesis* figure, students can watch animations, answer assessment questions, and interact with simulations to guide them through the illustration.