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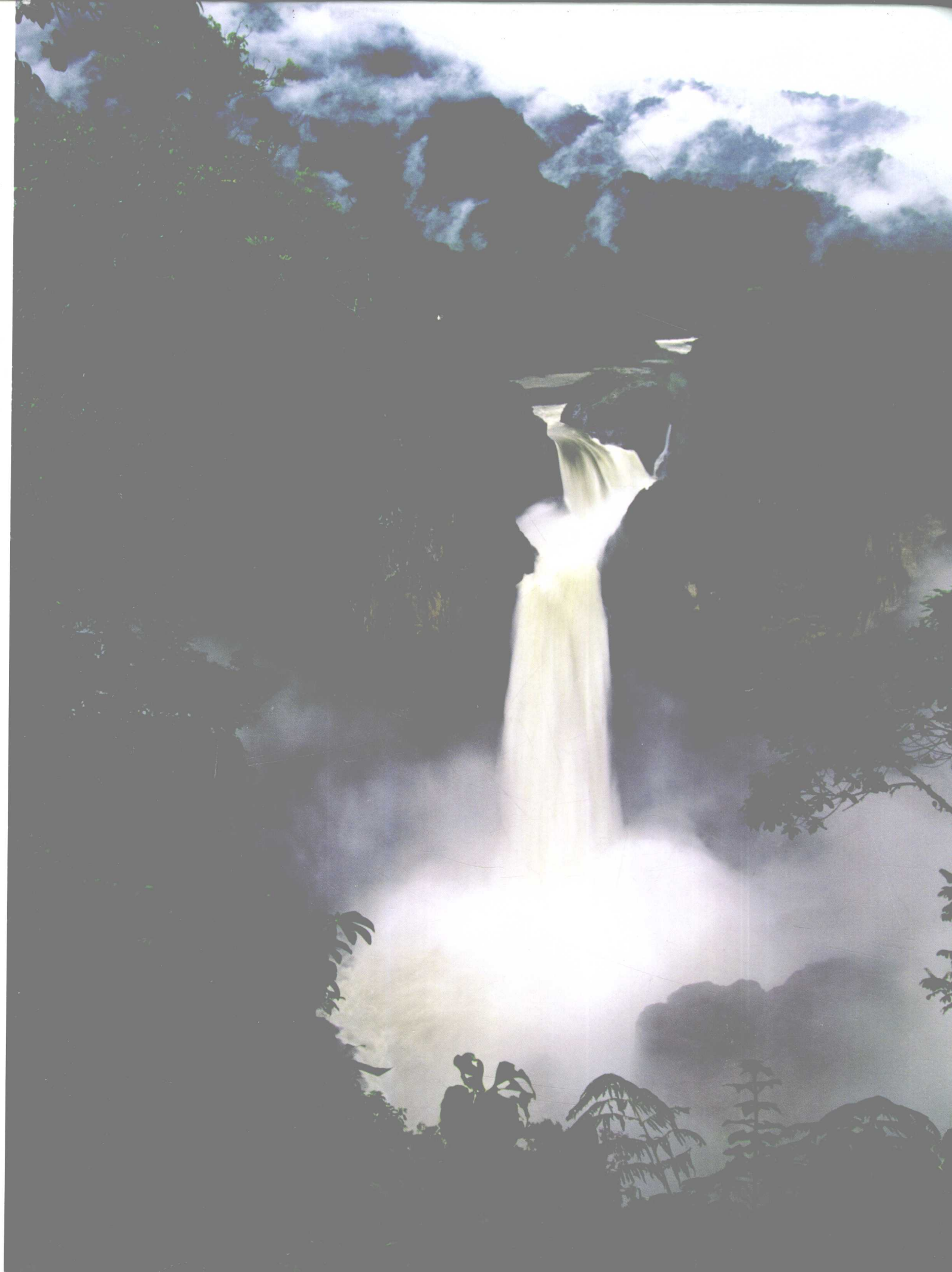

BIOLOGY

The Unity and Diversity of Life

TENTH EDITION

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PREFACE

Successive revisions of this book span nearly thirty years and reflect feedback from many instructors and students. This new edition retains the concept spreads and other pedagogical features that are the hallmarks of the book.

CONCEPT SPREADS Reading and absorbing textbook assignments for multiple courses in the same timeframe can overwhelm students. We make it easier for them to read about and understand biology by focusing on one concept at a time. We list key concepts on the first page of each chapter. Then we organize text, art, and evidence in support of each concept on two facing pages, at most. As shown below, each *concept spread* starts with a numbered tab and ends with a boldfaced summary of the key points. Students can preview the on-page summary before they read the concept spread. They can read it again to check whether they understand the key points before turning to the next concept.

Concept spreads also offer teachers flexibility in assigning topics to fit their course requirements. For example, those who spend less time on photosynthesis may bypass the spreads on properties of light and the chemiosmotic theory of ATP formation. They may or may not assign the Focus essay on the global impact of photosynthesis. All spreads and essays are part of a chapter story, but some offer more depth.

We incorporate headings within concept spreads to help students keep track of the hierarchy of information. Transitions between spreads help them follow the story. So does setting aside some details in optional illustrations for motivated students.

With concept spreads, students find assigned topics fast, and they can focus on manageable amounts of information. This makes them more confident in their capacity to absorb the material. Our approach has a tangible outcome—improved test scores.

VISUALIZING CONCEPTS We continue to develop text and art together, as an inseparable whole. Our *"read-me-first diagrams"* are a prime example of this approach. They allow visual learners to build a mental image of a concept before reading the text details about it. Figure 34.5 in the sample pages at right shows how simple descriptions walk students step by step through these preview diagrams. Many of our millions of student readers have written in to tell us that our approach helps them far more than a reliance on "wordless" diagrams.

Many *anatomical drawings* are integrated overviews of structure and function. Students need not jump back and forth from text, to tables, then to art, and back again to visualize how an organ system is put together and what its component parts do. We also use *zoom sequences*, from macroscopic to microscopic views, to move students visually into a system or process. For example, Figures 37.19 and 37.20 start with a ballerina's biceps and move on down through levels of skeletal muscle contraction.

Icons remind students of where art fits into the story line. For instance, icons of a cell remind students where

Gold numbered tabs, such as this one, identify the start of each new concept in a chapter. Other tabs (brown) in the chapter identify Focus essays. Many essays enrich the basic text by addressing medical, environmental, and bioethical issues. Others offer detailed examples of experiments to demonstrate the power of critical thinking.

Example of a cell icon

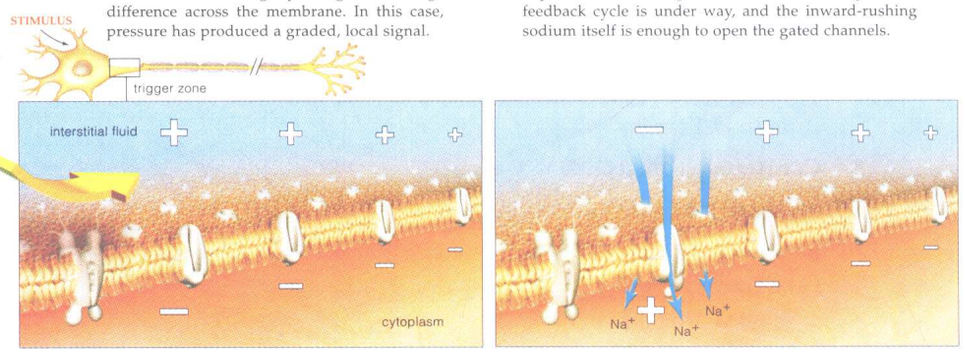
34.2

HOW ARE ACTION POTENTIALS TRIGGERED AND PROPAGATED?

Action potential propagation isn't hard to follow if you already know something about the gradients across the neural membrane. And so we now build on Section 34.1.

Approaching Threshold

When you weakly stimulate a neuron at its input zone, you disturb the ion balance across its membrane, but not much. Imagine putting a bit of pressure on the skin of a snoozing cat by gently tapping a toe on it. Tissues beneath the skin surface have receptor endings—input zones of sensory neurons. Patches of plasma membrane at these endings deform under pressure and let some ions flow across. The flow slightly changes the voltage difference across the membrane. In this case, pressure has produced a graded, local signal.



a Membrane at rest (inside negative with respect to the outside). An electrical disturbance (*yellow* arrow) spreads from an input zone to an adjacent trigger region of the membrane, which has a great number of gated sodium channels.

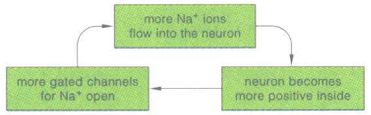
b A strong disturbance initiates an action potential. Sodium gates open. The sodium inflow decreases the negativity inside the neuron. The change causes more gates to open, and so on until threshold is reached and the voltage difference across the membrane reverses.

Figure 34.5 Propagation of an action potential along the axon of a motor neuron.

Graded means that signals arising at an input zone vary in magnitude. They are small to large, depending on the stimulus intensity or duration. *Local* means these signals do not spread far from the site of stimulation. Why? It takes certain kinds of ion channels to propagate a signal, and input zones simply don't have them.

When a stimulus is intense or long-lasting, graded signals spread from the input zone into an adjoining trigger zone. This patch of membrane is richly endowed with voltage-sensitive gated channels for sodium ions. *And this is where a certain amount of change in the voltage difference across the plasma membrane triggers an action potential.* The amount is the neuron's threshold level.

When these gates open, positively charged sodium ions flow into the neuron, as in Figure 34.5. With the influx of ions, the cytoplasmic side of the membrane becomes less negative. This causes more gates to open and more sodium to enter. The ever increasing, inward flow of sodium is a case of **positive feedback**, whereby an event intensifies as a result of its own occurrence:



At threshold, opening of sodium gates no longer depends on the strength of the stimulus. The positive-feedback cycle is under way, and the inward-rushing sodium itself is enough to open the gated channels.

An All-or-Nothing Spike

Figure 34.6 shows a recording of the voltage difference across the plasma membrane before, during, and after an action potential. Notice how the membrane potential peaks once threshold is reached. All action potentials in a neuron spike to the same level above threshold as an *all-or-nothing* event. Once a positive-feedback cycle starts, nothing stops full spiking. Unless threshold is reached, the membrane disturbance subsides when the stimulation ends, and an action potential won't occur.

Each spike lasts for only a millisecond or so. Why? At the patch of membrane where the charge reversed, gated sodium channels close and shut off the sodium inflow. And about halfway into the reversal, potassium

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its organelles are located, as in Chapter 4. Other icons remind students of how reaction stages interconnect in a metabolic pathway, as in Chapter 7 (photosynthesis) and Chapter 8 (aerobic respiration). Others remind them of evolutionary relationships, as in Chapters 25 and 26. A multimedia icon directs students to art in the CD-ROM packaged at the back of every book. Others direct them to supplemental material on the Web and to InfoTrac® College Edition, an online database of full-length articles from 4,000 academic journals and popular sources.

Finally, we added hundreds of new *micrographs and photographs*. These are not window dressing, tacked on after the fact. They sharpen the meaning of "biodiversity" and hint at why it is worth preserving.

BALANCING CONCEPTS WITH APPLICATIONS We draw students into each chapter with a lively or sobering application. That application gives way to a list of key concepts, an advance organizer. We attempt to maintain their interest with focus essays, which provide depth on medical, environmental, and social issues without interrupting the conceptual flow. Where we sense that the core material needs to be livened up a bit, we weave briefer applications into the text proper. On the last pages of the book, a separate Applications Index affords fast reference to our many hundreds of applications.

FOUNDATIONS FOR CRITICAL THINKING Like all textbooks at this level, ours helps students sharpen their capacity to think critically about nature. We walk them through experiments that yielded clear evidence in favor of or against hypotheses. The main index at the back of the book lists the experiments we selected (see the entries *Experiment, examples*, and *Test, observational*).

We also selectively use chapter introductions as well as entire chapters to show productive outcomes of critical thinking. The chapter introductions to Mendelian genetics (11), DNA structure and function (13), speciation (18), immunology (39), and behavior (46) are examples. The end of each chapter has a set of *Critical Thinking* questions. Numerous *Genetics Problems* at the end of Chapters 11 and 12 help students grasp principles of inheritance.

SUPPLEMENTS The Instructors' Examination copy for this edition lists a comprehensive package of print and multimedia supplements, including online resources that are available to qualified adopters. Please ask your local sales representative for details.

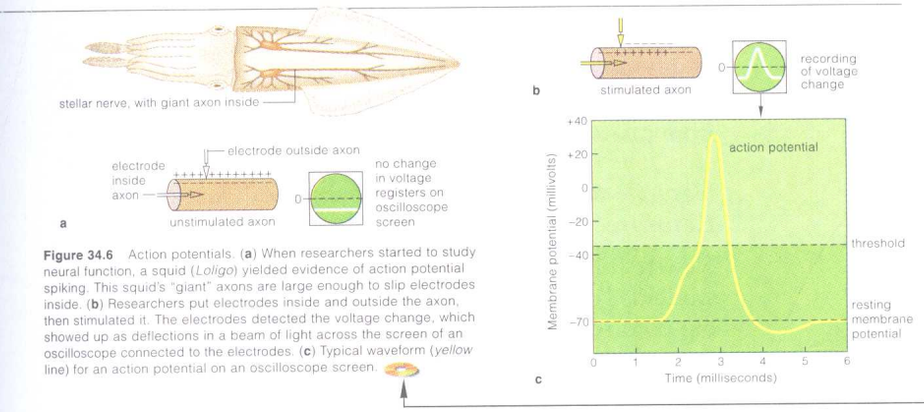
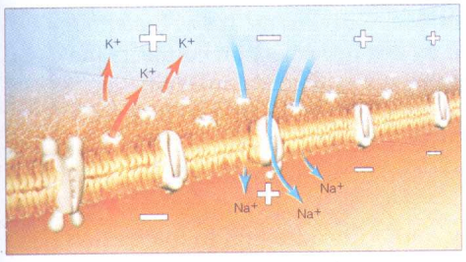
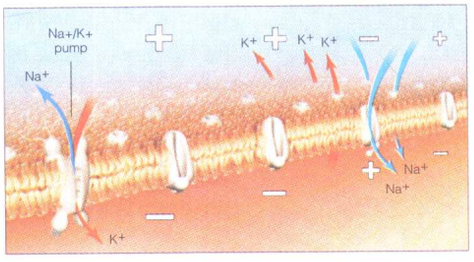


Figure 34.6 Action potentials. (**a**) When researchers started to study neural function, a squid (*Loligo*) yielded evidence of action potential spiking. This squid's "giant" axons are large enough to slip electrodes inside. (**b**) Researchers put electrodes inside and outside the axon, then stimulated it. The electrodes detected the voltage change, which showed up as deflections in a beam of light across the screen of an oscilloscope connected to the electrodes. (**c**) Typical waveform (*yellow line*) for an action potential on an oscilloscope screen.



c With the reversal, sodium gates shut and potassium gates open (*red* arrows). Potassium follows its gradient out of the neuron. Voltage is restored. The disturbance triggers an action potential at the adjacent site, and so on, away from the point of stimulation.



d Following each action potential, the inside of the plasma membrane becomes negative once again. However, the sodium and potassium concentration gradients are not yet fully restored. Active transport at sodium–potassium pumps restores them.

channels opened, so potassium flows out. This restores the voltage difference at the patch but not the original gradients. Sodium–potassium pumps actively transport sodium back outside and potassium inside. Once this is done, most potassium gates close and sodium gates are in their original position—ready to be opened with the arrival of a suitable signal at the membrane patch.

The Direction of Propagation

During an action potential, the inward rush of sodium ions affects the charge distribution across the adjacent membrane patch, where an equivalent number of gated channels open. Gated channels open in the *next* patch, and the next, and so on. This positive feedback event is self-propagating and does not diminish in magnitude. You might be wondering: Do action potentials spread back to the trigger zone? No. For a brief period after the inward rushing of sodium ions, the voltage-gated channels remain insensitive to stimulation, so sodium ions cannot move through them. This is one reason why action potentials do not spread back to the patch of membrane where they were initiated. It is why they propagate themselves away from it.

Ions cross the neural membrane through transport proteins that serve as gated or open channels. At a suitably disturbed trigger zone, sodium gates open in an all-or-nothing way, and the inward-rushing sodium causes an action potential. Sodium–potassium pumps restore the original ion gradients.

Sodium gates across the membrane are briefly inactivated after an action potential, which is one reason why an action potential is self-propagating away from a trigger zone.

This icon signifies that we explore the concept further on our interactive CD-ROM.

This is an example of our "read-me-first" diagrams for visual learners. They are illustrated previews of the text material, complete with simple "a b c" descriptions that guide the student each step of the way.

Boldfaced key concepts end each tabbed section. Students can read them to preview the section's main points, then read them again to reinforce what they learn from the section.

All together, these highlighted statements are a running summary of the take-home lessons.

This icon reminds students to check out the website, which expands on the section's topic.

A MAJOR CONCEPTUAL SHIFT In the past, with each revision, we have updated details to reflect new work in biology's rapidly changing fields. This time we did more. We decided to undertake a major conceptual shift after concluding that one is long overdue in biology textbooks at this level.

The Emerging Big Picture

Biology's overriding paradigm is one of interpreting life's spectacular diversity as having evolved from simple molecular beginnings. For decades now, researchers have been chipping away at the structural secrets of biological molecules. They have discovered how different kinds are put together, how they function, and what happens when they mutate. They are casting light on how life originated, what happened during the past 3.8 billion years, and what the future may hold for humans and other organisms, individually and collectively.

This is profound stuff. *Yet introductory textbooks—including previous editions of this one—have not given students enough information to understand the remarkable connection between molecular change, evolution, and their own lives.* We rebuilt much of this tenth edition to show the connection more clearly, starting with the new models for biological molecules. The models can give students a deeper appreciation of how *structural* diversity translates into *functional* diversity.

Powerful Conceptual Tools for Students

Molecular models appear in books, newspapers, and popular magazines, but few students have a clue to what they represent. Why even ask them to memorize the fact that polypeptide chains form coils, sheets, and loops without giving clear examples of the outcomes? Why not show how different configurations form, say, membrane-spanning barrels, anchors, or jaws that grip enemy agents in the body? Why not complete the point and say that mutation may alter a configuration just enough to block or enhance a transport or anchoring or defensive function?

And why not connect that point with the paradigm? *Small changes in molecular sequences and functional domains give rise to variation in traits—the raw material of evolution.*

Once the connection becomes clear, students can apply what they learn about changes in molecular structure to many of their questions and concerns about life. Genetic disorders? Look to modifications in molecular structure that have altered how cells, organs, and the organism itself function. Events that long ago put chimpanzees and humans on their separate evolutionary paths? Look to transposons and other disruptions in shared ancestral DNA. Differences in the number of legs on a fly or centipede or human, or the number of petals on a flower? Look to small mutations in master genes that control development of the basic body plan.

And what about similarities in how, say, tulips and Tina Turner or any other organism function? Look to commonalities in molecular responses to environmental challenges.

Chapters That Develop the Conceptual Tools

Several chapters build on one another to help students develop knowledge of the molecular basis of life. The first chapter is a simple preview of the molecular basis of life's unity and diversity. Chapters 3, 5, and 6 have sections on the structure and function of enzymes and other molecules that prepare students for the important chapters on cell structure and metabolism, genetics, evolution, anatomy, and physiology.

For instance, with this background, students can sense the power of comparative molecular studies in clarifying evolutionary relationships. Among the outcomes of such studies are refined evolutionary tree diagrams and the three-domain classification system.

Chapter 28 is a new prelude to the units on anatomy and physiology. It points out that we sometimes forget how much plants and animals have in common at the molecular level, because their body plans are so different. For example, one of the essays in this chapter focuses on recurring challenges to survival of *all* individual cells in the multicelled body—specifically, the requirements for gas exchange and internal transport, for homeostasis in the internal environment, and for integration and control. This chapter also starts students thinking about how cells communicate with one another, using simple examples of signal reception, transduction, and response from plants and animals.

New Connections Essays That Reinforce the Big Picture

New to this edition are Connections essays that can help students "connect the dots" between text details and big-picture concepts. The facing page lists these essays.

Setting the Stage

Connections essay 1.4 answers a central question: How can life display both unity *and* diversity? It suggests that the theory of evolution by natural selection connects the two. Obviously, we cannot get into actual mechanisms of evolution until after the book's units on cell biology and genetics. But a simple outline of the theory can help students connect its basic premises with the topics of those units as well.

Essay 3.1 is a user-friendly introduction to the models that represent biological molecules. Most textbooks show molecules as sticks, balls, ribbons, and bubbled blobs. How many students stare blankly at them? We let them in on an unfortunately well-kept secret. Different models convey different information, such as mass, structural organization, reactivity, or function. That is why we use different kinds in different contexts. For example, the models for glycogen, hemoglobin, enzymes, and DNA tell us different things about how cells and organisms are put together and how they function.

Without this knowledge, can students extrapolate from molecular models to generic icons—to the circles and squares used to represent enzymes, ATP, and all the other biological molecules? Can they really extrapolate from generic icons alone to the concept of structure, function, and evolution? We think not.

Essay 5.2, for example, showcases some important membrane proteins. These stunning models make it easier for students to recognize that structural diversity translates into the functional diversity necessary for metabolism, gene function, integration, immunity, the formation of tissues and organs, and other tasks. They make it possible to comprehend how, say, cystic fibrosis arises from a mutation that changes the function of just one kind of membrane transporter. As another example, Essay 3.8 moves students from the molecular structure of HbA to HbS, and on to sickle-cell anemia.

Making Sense of Evolution and Biodiversity

Unless we explain continuity and change at the molecular level convincingly enough, many students will never become open to the idea of continuity and change in life itself—to the possibility that evolution is more than "just a theory."

Continuity and change—Essay 8.7 picks up on this thought. It ties together concepts from the cell biology unit into a view of how all of life connects as a result of evolution at the molecular level.

Essay 19.9 reinforces a major point—that interpreting the past scientifically requires a huge intellectual shift, from direct observation to inferences based upon molecular studies, the fossil record, and morphological comparisons. Essay 28.2 picks up on the same thought. The essay invites caution in interpreting the evolutionary history of life, because "adaptations" are not always what they seem. Its comparison of llama and camel hemoglobin underscores the point.

With tentative acceptance of evolutionary theory, students can think about applying it to their own lives. Essays 26.2, 26.11, 37.4, and 38.1 interconnect in this respect. They hint at where our amazing brains and hands came from, why we have such intricate highways for blood circulation through our body, and why we are prone to lower back pain. Essay 34.12 connects the brain's evolutionary history with its development. It shows how that connection helps explain why teenagers tend to fall asleep in class and engage in notably impulsive behavior.

Acceptance also gives broad insight into the source of biodiversity, into mass extinctions and slow recoveries. Essays 21.9, 22.1, 23.1 reinforce this point.

Connecting Our Lives to the Big Picture

Deeper understanding of how each of us connects with the sweeping story of life—that is what we hope students will take away from their introduction to biology. With this in mind, we use some essays to show how biology impacts our own lives and the choices that we make.

Essay 16.10, for example, reflects on how the ability to study and alter genomes rapidly, as with the use of DNA microarrays, is outpacing our attempts to assess its bioethical implications. What are the ramifications of human gene therapy? Cloning genetically engineered mammals? Manipulating genomes of crop plants? These are issues facing students today, and the citizens and leaders of tomorrow.

At the end of Unit V, which shows what it takes to be a plant, Essay 32.6 considers one of the costs of growing enough plants to feed the human population. It invites students to think about how we have become locked into using herbicides, fungicides, and pesticides on a massive scale. It invites them consider the effect of these complex molecules on nontargeted organisms, including us.

As two more examples, Essay 49.14 recounts how Rita Colwell made a sweeping connection between copepods, a bacterial life cycle, sea surface temperature changes during El Niño episodes, and horrible cholera outbreaks in Bangladesh.

The essay in our concluding chapter 50 compares life's evolution over the past 3.8 billion years with the impact of relative latecomers—humans. It asks students to think about the bioethics of mitigating the disproportionate effect of we latecomers on the world of life.

CONNECTIONS ESSAYS

Vertical red bands down the edge of a text page flag these essays.

OTHER MAJOR CHANGES Now that systematists have reached consensus, we have subsumed the kingdoms of organisms into the three-domain classification system. Section 1.3 introduces the system; Sections 19.7 and 19.8 fill in details. We took a stronger cladistic approach and did major work on the chapters of the biodiversity unit. Section 22.1 gives the rationale for doing so. The outcome is most evident in how we present the protistans (Chapter 22) and vertebrates (Chapter 26).

Again, we moved away from generic boxes and circles for molecules and present more realistic models for membranes, protein transporters, enzymes, RNAs, and other cell components. You can check out some examples of how we put them to use in Chapters 3, 5, 14, and 34.

To give an idea of what went into the new graphics, Lisa Starr rendered our molecular models from primary structural data. She even tracked down researchers who are still constructing a model of the human cardiac gap junction and worked directly with them to convert their most recent data into graphic form for this book.

We rewrote Section 13.5 (mammalian cloning) and Chapter 16 (recombinant DNA and genetic engineering) to keep up with the rapid advances in biotechnology. Section 16.10 addresses some of the bioethical issues. So do some of the detailed *Critical Thinking* questions at the end of Chapter 16. These are serious issues that should provoke discussion among students. The Chapter 15 introduction and focus essay on cancer are updated.

Given the wealth of new information to be covered in the evolution unit, we decided to condense the history of evolutionary thought into a few introductory sections for Chapter 17 (microevolution). Chapter 19 (macroevolution) is heavily rewritten and reorganized, starting with a new introduction on issues associated with measuring geologic time. There is stronger treatment of the evidence from comparative biochemistry and systematics. This chapter concludes with a reflection on how we interpret the past.

I urge our adopters to review Chapter 28. Concepts that will help students get through the two units on plant and animal anatomy/physiology are presented here. We have made so many refinements and updates—for example, on human nutrition, embryonic development, and predator–prey interactions, but we are running out of room to highlight them all. Suffice it to say that we made an honest, solid attempt to keep up with biology and to do it justice all across the board.

Writing this preview of all the changes reminded me again of how fortunate I am to be under the Wadsworth umbrella. No author can execute a huge revision every single time without a dedicated production team and enlightened management. Gary Head, Lisa Starr, Diana Starr, Suzannah Alexander, Jana Davis, Teri Hyde, Karen Hunt, Grace Davidson, Myrna Engler, Angela Harris—this is my core team, the best of the best. Pat Waldo, Donna Kelley, Keli Amann, Chris Evers, Steve Bolinger—they create our stunning multimedia package. Susan Badger, Sean Wakely, Michelle Julet, Jack Carey, Kathie Head—these are anomalies in higher education, publishers who nurture authors with intelligence, strength, and grace.

Cecie Starr, October 2002
E-mail starr@brookscole.com

ACKNOWLEDGMENTS

This book is the current version of an educational effort that started nearly three decades ago. We thank all of the students and instructors who used and commented on previous editions. We thank the individuals listed here for their significant influence on the book's development. We give special thanks to this edition's overall advisor, E. William Wischusen, who helped formulate connections to remind students of where they have been and where they are going in the book. As he pointed out, if we expect them to understand the chapters on genetics, evolution, anatomy, and physiology, we must provide them with the intellectual tools and graphics to do so. We must clearly connect chapters back to the tools that guide students through biomolecules and membranes. And we must include a new chapter on the commonalities between plant and animal systems to help students see the big picture while learning the details.

We also thank Walter Judd, who guided our overhaul of the macroevolution and biodiversity chapters, with close attention to the protistans and vertebrates. The new evolutionary tree diagram (Sections 19.8 and 22.1) and classification system (Appendix I) are his contributions.

If teachers appreciate the new clarity of thought and currency of this new edition, they might give a special nod of recognition to Bill and Walt for urging us gently to give it our best shot—and then to keep on giving more.

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