



# BIOLOGY

*concepts and applications*

FOURTH EDITION

CECIE STARR



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PROJECT DEVELOPMENT EDITOR: Kristin Milotich

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DEVELOPMENTAL EDITOR: Mary Arbogast

MARKETING MANAGER: Tami Cueny

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PRINT BUYER: Karen Hunt

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TEXT AND COVER DESIGN, ART DIRECTION: Gary Head,  
Gary Head Design

ART COORDINATORS: Myrna Engler, Mary Douglas

EDITORIAL PRODUCTION: Karen Stough, Mary Wininger

PRIMARY ARTISTS: Lisa Starr; Raychel Ciemma; Precision  
Graphics, Preface Inc. (Jan Flessner)

ADDITIONAL ARTISTS: Robert Demarest, Darwen Hennings,  
Vally Hennings, Betsy Palay, Nadine Sokol, Kevin  
Somerville, Lloyd Townsend

PHOTO RESEARCH, PERMISSIONS: Roberta Broyer

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### International Headquarters

Thomson Learning  
290 Harbor Drive, 2nd Floor  
Stamford, CT 06902-7477, USA

### UK/Europe/Middle East

Thomson Learning  
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168-173 High Holborn  
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### Australia

Nelson/Thomson Learning  
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Building 18, Constantia Park  
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# PREFACE

Teachers of introductory biology know all about the Red Queen effect, whereby one runs as fast as one can to stay in the same place. New and modified information from hundreds of fields of inquiry piles up daily, and somehow teachers are expected to distill it into Biology Lite, a one-course zip through the high points.

This book is a coherent account of the sweep of life's diversity and its underlying unity, although we structured it in such a way that teachers can easily and selectively assign chapters from it. The book highlights concepts, current understandings, and research trends for all major fields of inquiry. Through examples of problem solving and experiments, it shows the power of thinking critically. It explains the structure and function of a broad sampling of organisms in enough detail so students can develop a working vocabulary about life's parts and processes.

The book starts with an overview of basic concepts and methods. Three units on the principles of biochemistry, inheritance, and evolution follow; they are the conceptual framework for exploring life's unity and diversity, starting with an evolutionary survey of each kingdom. Units on

comparative anatomy and physiology of plants, then of animals, are next. The last unit focuses on patterns and consequences of organisms interacting with one another and with the environment. This conceptual organization parallels the levels of biological organization.

**CONCEPT SPREADS** We keep the story line in focus for students by subscribing to the question "How do you eat an elephant?" and its answer, "One bite at a time." In this book students will find descriptions, art, and supporting evidence for each concept organized on two facing pages, at most. Each "concept spread" starts with a numbered tab and ends with boldface, summary statements of key points (*see below*). Students can use the statements to check whether they understand the concepts of one spread before starting another.

Writing that rambles quickly kills interest in any topic. Restricting the space available for each concept forced us to avoid the clutter of superfluous detail. Also, ongoing feedback from teachers of more than three million students guided our decisions about when to leave core material alone and when to loosen it up with applications. Within each spread, headings and subheadings help students track the hierarchy of information. Carefully crafted transitions between spreads help them keep the greater story in focus

To keep readers focused, we present each concept on one or two facing pages, starting with a numbered tab . . .

## 38.12 FORMATION OF THE EARLY EMBRYO

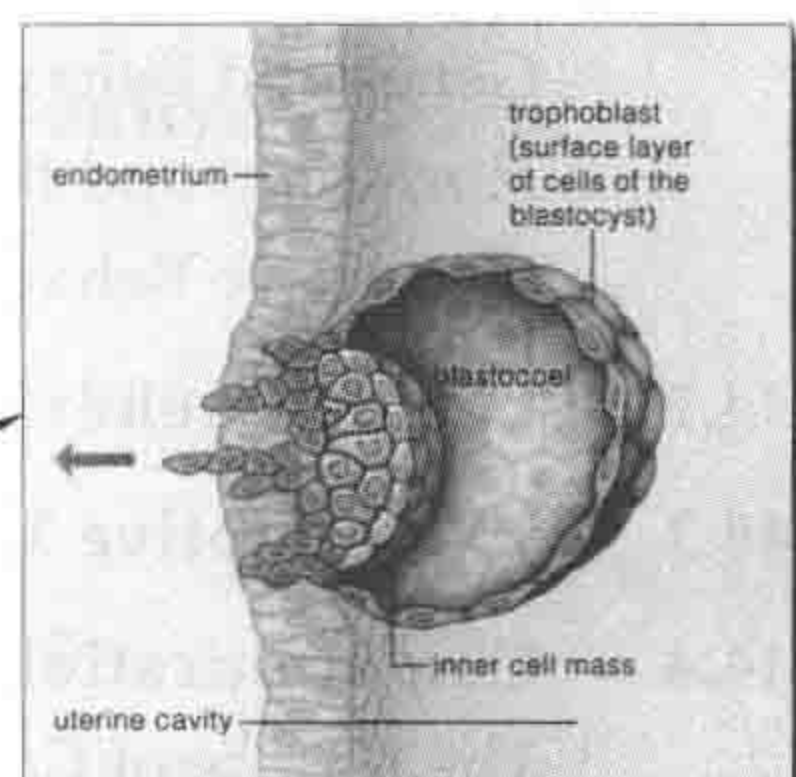
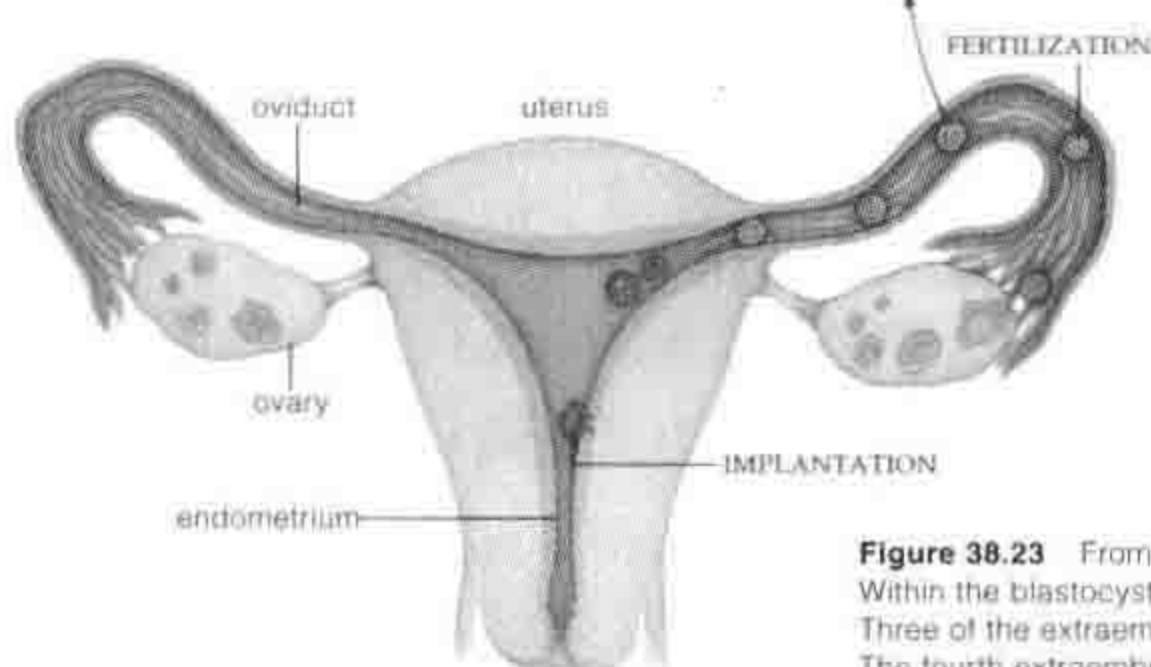
Pregnancy lasts an average of thirty-eight weeks from the time of fertilization. It takes about two weeks for a blastocyst to form. The time span from the third to the end of the eighth week is the *embryonic period*, when the major organ systems form. When it ends, the new individual has distinctly human features and is called a *fetus*. In the *fetal period*, from the start of the ninth week until birth, organs enlarge and become specialized.

**d DAYS 3.** A blastocoel (a fluid-filled cavity) forms in the morula as a result of secretions from the surface cells. By the thirty-two-cell stage, cells of an inner cell mass are already differentiating. They will give rise to the embryo proper. This embryonic stage is called a blastocyst.

**c DAY 4.** By 96 hours, there is a ball of sixteen to thirty-two cells that is shaped like a mulberry. It is a morula (after *morum*, Latin for mulberry). Cells of the surface layer will function in implantation and will give rise to a membrane, the chorion.

**b DAY 3.** After the third cleavage, the cells suddenly huddle together into a compacted ball, which becomes stabilized by numerous tight junctions among the outer cells. Gap junctions form among the interior cells and enhance intercellular communication.

**a DAYS 1-2.** Cleavage begins within 24 hours after fertilization. The first cleavage furrow extends between the two polar bodies. Subsequent cuts are rotational, so the resulting cells are not symmetrically arranged (compare Section 35.3). Until the eight-cell stage forms, the cells are loosely arranged, with considerable space between them.



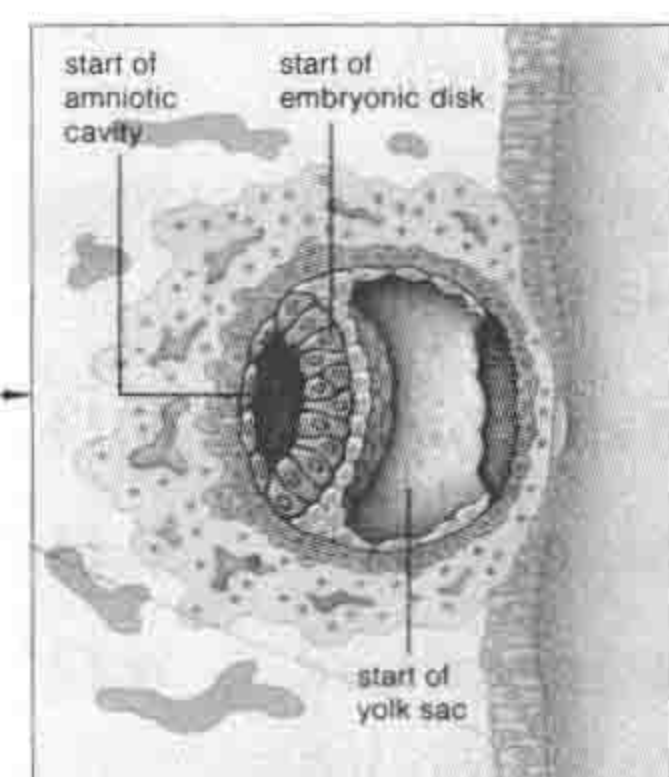
**e DAYS 6-7.** Surface cells of the blastocyst attach to the endometrium and start to burrow into it. Implantation is under way.

We typically call the first three months of pregnancy the *first trimester*. The *second trimester* extends from the start of the fourth month to the end of the sixth. The *third trimester* extends from the seventh month until birth. Beginning with Figure 38.23, the next series of illustrations shows the characteristic features of the new individual at progressive stages of development.

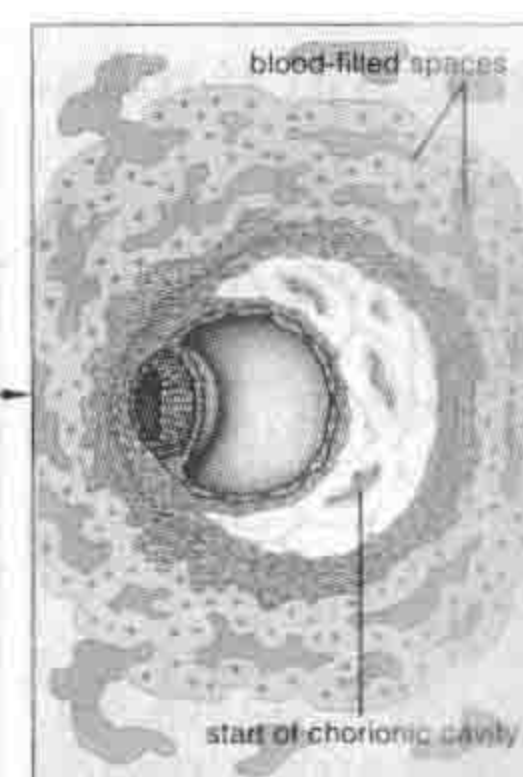
### Cleavage and Implantation

Three to four days after fertilization, the zygote is already undergoing cleavage as it tumbles through the oviduct. Genes are already being expressed; the early divisions depend on their products. At the eight-cell stage, the cells huddle into a compact ball. By the fifth day, there is a surface layer of cells (a trophoblast), a cavity filled with their secretions (a blastocoel), and a tiny cluster of interior cells (an inner cell mass). These are the defining features of a human blastocyst (Figure 38.23d).

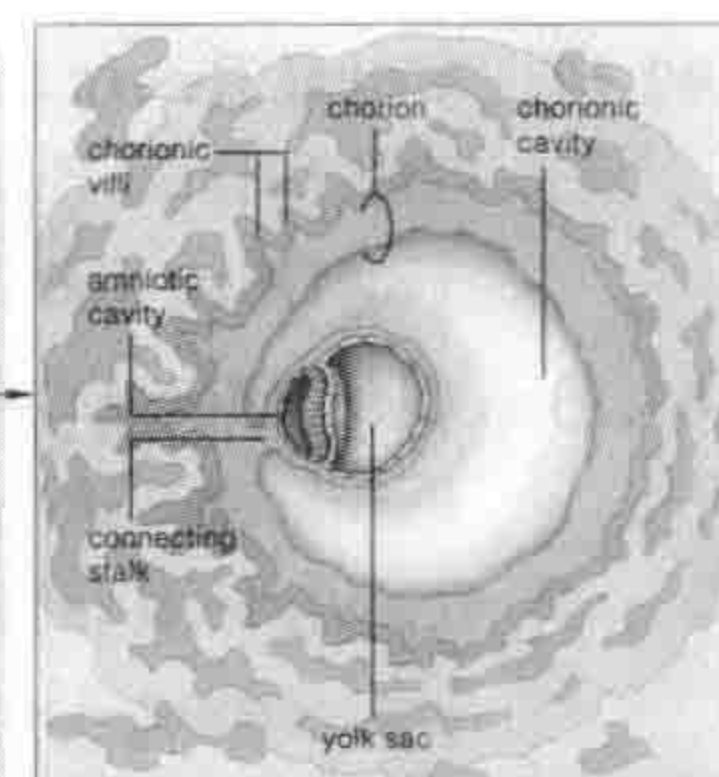
Six or seven days after fertilization, **implantation** is under way. By this process, the blastocyst adheres to the uterine lining, some of its cells send out projections that invade the mother's tissues, and connections start forming that will metabolically support the developing embryo through the months ahead. While the invasion is proceeding, the inner cell mass develops into two



**f DAYS 10-11.** The yolk sac, embryonic disk, and amniotic cavity have started to form from parts of the blastocyst.



**g DAY 12.** Blood-filled spaces form in maternal tissue. The chorionic cavity starts to form.



**h DAY 14.** A connecting stalk has formed between the embryonic disk and chorion. Chorionic villi, which will be features of a placenta, start to form.

cell layers of a flattened and somewhat circular shape. The two layers make up the embryonic disk—and in short order they will give rise to the embryo proper.

### Extraembryonic Membranes

As implantation progresses, membranes start to form outside the embryo. First a fluid-filled *amniotic* cavity opens up between the embryonic disk and part of the blastocyst's surface (Figure 38.23f). Then cells migrate around the wall of the cavity and form the *amnion*, a membrane that will enclose the embryo. Fluid inside the cavity will function as a buoyant cradle where the embryo can grow, move freely, and be protected from abrupt temperature changes and mechanical impacts.

While the amnion forms, other cells migrate around the inner wall of the blastocyst's first cavity. They form a lining that becomes the *yolk sac*. This extraembryonic membrane speaks of the evolutionary heritage of land vertebrates (Sections 24.7 and 24.8). For most animals that produce shelled eggs, the sac holds nutritive yolk. In humans, part of the yolk sac becomes a site of blood cell formation, and part will give rise to germ cells, the forerunners of gametes.

Before the blastocyst is fully implanted, spaces open in maternal tissues and fill with blood seeping in from ruptured capillaries. Inside the blastocyst, another cavity opens around the amnion and yolk sac. Now fingerlike projections start to form on the cavity's lining, which is the *chorion*. This new membrane will become part of a spongy, blood-engorged tissue called the placenta.

After the blastocyst is finally implanted, another extraembryonic membrane will form as an outpouching of the yolk sac. This third membrane will become the *allantois*. An allantois functions differently in different animal groups. Among reptiles, birds, and some of the mammals, it has roles in respiration and in the storage of metabolic wastes. In humans, the urinary bladder as well as blood vessels for the placenta form from it.

One more point should be made here. Cells of the blastocyst secrete the hormone HCG (Human Chorionic Gonadotropin), which stimulates the corpus luteum to keep on secreting progesterone and estrogen. Thus the blastocyst itself prevents menstrual flow and works to avoid being sloughed off until the placenta takes over the task, some eleven weeks later. By the start of the third week, HCG can be detected in the mother's blood or urine. At-home *pregnancy tests* use a treated "dipstick" that changes color when HCG is present in urine.

A human blastocyst is composed of a surface layer of cells around a fluid-filled cavity (blastocoel) and an inner cell mass, which will give rise to the embryo proper.

Six or seven days after fertilization, the blastocyst implants itself in the endometrium. Now projections from its surface invade maternal tissues, and connections start to form that in time will metabolically support the developing embryo.

Some parts of the blastocyst give rise to an amnion, yolk sac, chorion, and allantois. These extraembryonic membranes serve different functions. Together they are vital for the structural and functional development of the embryo.

. . . and ending with one or more summary statements.



and discourage memorization for its own sake. Also, for interested students, we integrate details that could disrupt the text's conceptual flow into optional illustrations.

Based on extensive user feedback, we know that our clearly defined organization helps students find assigned topics easily and translates into improved test scores.

**BALANCING CONCEPTS WITH APPLICATIONS** Each chapter starts with a lively or sobering application and an adjoining list of key concepts (the chapter's advance organizer). Strategically placed examples of applications parallel core material, not so many as to be distracting, but enough to keep minds perking along with the conceptual development. Many brief applications are integrated in the text. Others are in focus essays that afford more depth on medical, environmental, and social issues for interested students but do not interrupt the text. The book's last four pages separately index all applications for quick reference.

**FOUNDATIONS FOR CRITICAL THINKING** To help students increase their capacity for critical thinking, we walk them through experiments that yielded evidence in favor of or against hypotheses. The main index lists all experimental tests and observational tests (see the entries *Experiment* and *Test, observational*).

We use certain chapter introductions as well as entire chapters to show students some of the productive results of critical thinking. The introductions to Mendelian genetics (Chapter 10), DNA structure and function (12), speciation (17), immunology (34), and behavior (44) are examples.

Each chapter concludes with a set of *Critical Thinking* questions. Katherine Denniston developed most of those thought-provoking questions. Daniel Fairbanks developed many of the *Genetics Problems*, which help students grasp the principles of inheritance (Chapters 10 and 11).

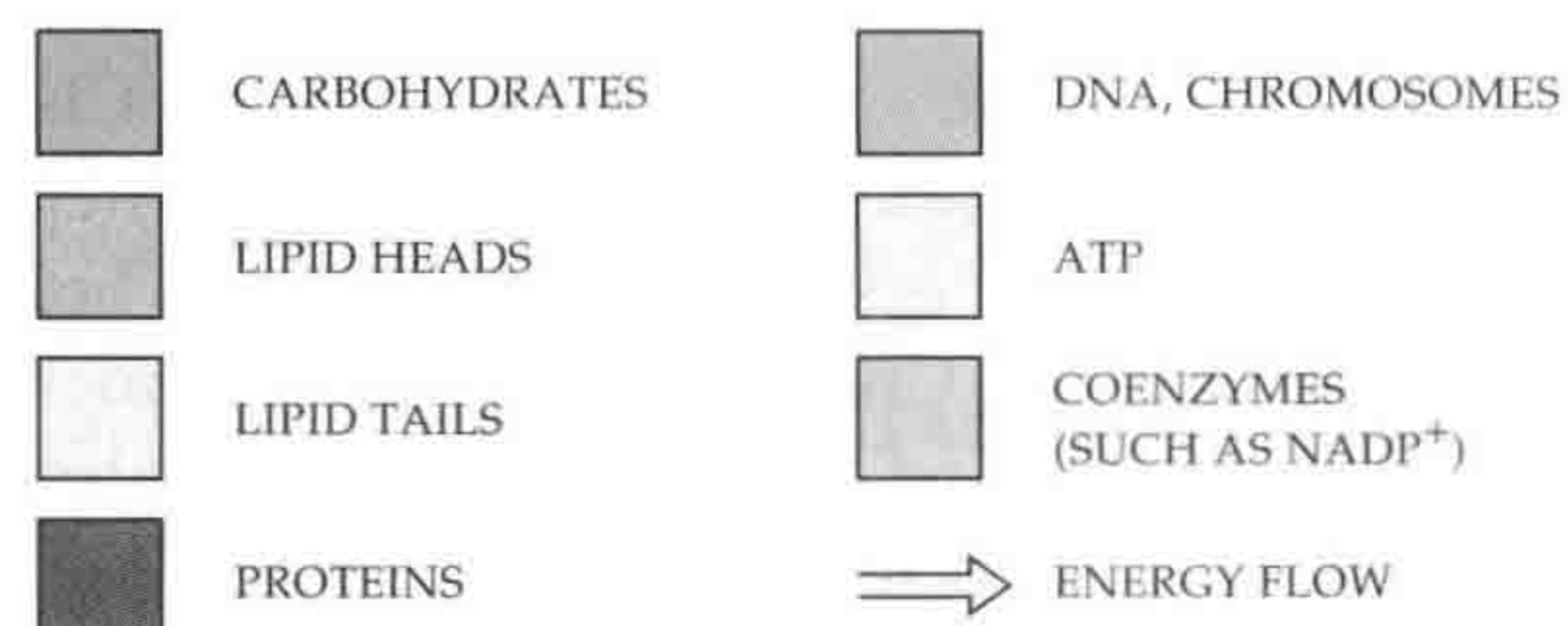
**VISUAL OVERVIEWS OF CONCEPTS** We simultaneously develop the text and art as inseparable parts of the same story. We also give visual learners a means to work their way through a visual overview of a major process before reading the corresponding text, which thereby becomes less intimidating. Students repeatedly let us know how much they appreciate this approach.

Our overview illustrations have step-by-step, written descriptions of biological parts and processes. Instead of "wordless" diagrams, we break down information into a series of illustrated steps. For example, the descriptions of Figure 13.10, integrated with the art, walk students step at a time through the stages by which a mature mRNA transcript becomes translated.

Many anatomical drawings are integrated overviews of structure and function. Students need not jump back and forth from text, to tables, to illustrations, and back again in order to comprehend how an organ system is put together and what its parts do. Individual descriptions of parts are hierarchically arranged to reflect the structural and functional organization of the system.

**ZOOM SEQUENCES** Many illustrations progress from macroscopic to microscopic views of the same subject. Figure 7.2 is an example. It shows where the reactions of photosynthesis proceed, starting with a plant leaf. Figures 32.15 and 32.16 start with a human arm and move down through levels of skeletal muscle contraction.

**COLOR CODING** Visual consistency throughout the book helps students track complex parts and processes. Our line illustrations consistently use the same colors for each kind of molecule and cell structure:



**ICONS** Small diagrams next to an illustration help students relate a topic to the big picture. For instance, a simple representation of a cell subtly reminds students of the location of the plasma membrane relative to the cytoplasm. Other icons serve as reminders of the location of cellular reactions and processes, and of how they relate to one another. Still other icons remind students of the evolutionary relationships among groups of organisms, as in Chapters 23 and 24.

A multimedia icon directs students to art in a CD-ROM enclosed in their book. Another icon directs them to the supplemental material on the Web and a third, to InfoTrac:

CD-ROM  
ICON:



WEB  
ICON:



INFOTRAC  
ICON:



**CONTENT REVISIONS** For this edition we refined text and art in each concept spread and improved transitions between spreads. Overall, we tightened the writing but expanded certain topics that can be confusing if presented in insufficient detail. Chapters have crisper evolutionary story lines, a more balanced text-to-art ratio, and updated applications. Adjustments in the overall framework for the book reflect research trends. For example, in abidance with an emerging consensus, we subscribe to a six-kingdom classification scheme.

**INTRODUCTION** The Chapter 1 conceptual overview for the book is more focused, starting with introductions to the molecular trinity (DNA to RNA to protein), energy, and levels of biological organization. An early look at biodiversity reflects the six-kingdom model. A new, simple explanation of evolution by natural selection, a dominant theme for the book, follows. Chapter 1 now introduces scientific methods and the value of thinking critically in more depth and with more straightforward definitions.



To highlight the power of scientific inquiry, we have a new section on experimental tests of an alternative to antibiotics. This example builds on the chapter's earlier description of natural selection for antibiotic resistance. New *Critical Thinking* questions expand on the chapter discussion of scientific methods.

**UNIT I. PRINCIPLES OF CELLULAR LIFE** Basic chemistry is divided into two more manageable chapters. The first starts with a vignette on elements that have accumulated in the environment and are targets of phytoremediation, as at Chernobyl. We moved the radiometric dating portion of an essay on radioisotopes to the evolution unit. We revised the section on acids, bases, and buffers. Table 2.2 summarizes terms the student will use often. Chapter 3 starts with a carbon story (changes in atmospheric CO<sub>2</sub>), and has a new essay on pesticides and better coverage of proteins. Chapter 4 has updated material on the cytoskeleton and cell surface specializations.

Chapter 5 starts with a vignette on an application of bioluminescence. Simpler text and livelier illustrations make bioenergetics (a generally unloved topic) less intimidating. The chapter includes a refined treatment of membrane transport mechanisms.

New Chapter 6 art clearly shows the flow of hydrogen ions between the light-dependent and light-independent reactions. It has new icons, a new section on the properties of light and photosynthetic pigments, a visual comparison of carbon-fixing adaptations, and a new essay on light at Chapter 7 has new art and a livelier, updated treatment of alternative energy sources in humans and other mammals.

**UNIT II. PRINCIPLES OF INHERITANCE** New section 8.5 introduces chromosome structure earlier in the book and expands on the cell cycle to set the stage for later chapters. Chapter 9 has new art on crossing over and gametogenesis. Chapter 10 has cleaner definitions of many genetics terms and rewrites on pleiotropy and phenotypic variation. New to Chapter 11 is a vignette that uses a new karyotyping method to introduce the concept of genetic analysis (the progeria story moved to a Focus essay). The sections on karyotyping, linkage, and crossing over are rewritten. Sections on inheritance patterns as well as changes in chromosome number and chromosome structure contain new art and updated examples. More realistic art in the human genetics essay gets across the risk potential of amniocentesis and fetoscopy.

Chapter 12 has a new essay on Rosalind Franklin, a closer look at DNA replication, and a new essay on animal cloning. Sections on chromosome organization and on cancer moved to Chapters 9 and 14, respectively. Chapter 13 has a new tRNA model and icon for the art on protein synthesis. More art and a few more text examples make the mutation section easier to understand.

Sections on gene control are now in a separate chapter (14) that starts with a vignette on cancer. Text descriptions and definitions are crisper, particularly with respect to eukaryotic controls. The concluding essay that provides a closer look at cancer includes material on apoptosis.

Chapter 15 is reorganized, rewritten, and illustrated with striking new art. The changes include new material on DNA fingerprinting, automated DNA sequencing, gene isolation, mapping the human genome, and safety issues.

**UNIT III. EVOLUTION** Chapter 16 clarifies the influence of theories of catastrophism and uniformity on evolutionary thought. Chapter 17 has a tighter section on the biological species concept and reproductive isolating mechanisms. It has new art and text on allopatric speciation on archipelagos and other speciation routes, as by polyploidy. The extinction section is revised.

Chapter 18 is reorganized to separate the material on biological and geologic change. The geologic time scale and the comparative biochemistry section are revised. The five-kingdom and six-kingdom classification schemes are compared. A new section on plate tectonics and an essay on radiometric dating set the stage for the story of Earth's early evolution in next unit.

**UNIT IV. EVOLUTION AND DIVERSITY** Besides being a conceptual and chronological framework for the diversity chapters, survey Chapter 19 may help students sense their place in nature. Its tree of life reflects the six-kingdom scheme. Ediacaran and Cambrian forms are defined.

Chapter 20 has new material on the nature of bacterial growth and reproduction by prokaryotic fission. Detailed data in the old table on bacterial classification is now in Appendix I. The generalized viral multiplication cycle is revised for clarity. There is an essay on viroids and prions. Protistans get a more informative introduction. The essay on the nature of infectious diseases is expanded, with an evolutionary thrust. The algae are allocated a bit more text and new art (including a red algal life cycle).

Fungi now have their own chapter (21), which starts and ends with the concept of mutualism. The adaptive value of producing staggering numbers of spores is more clearly explained. The Chapter 22 section on evolutionary trends has new art and revised text. There is a new photo and description for peat bogs, a bit more on Carboniferous swamp forests, and more on seed-bearing plants (such as an essay on deforestation and a new concluding essay on seed plants and people).

Chapter 23 has new anatomicals for cnidarians and crustaceans, a section on cephalopod evolution, and a critical thinking question on rotifers. Its introduction to protostomes and deuterostomes is simply stated. Chapter 24 includes new illustrations (of a coelacanth, *Maiasaura*, chimpanzee big toe, and new diagrams (of the evolution of swim bladders and lungs; crocodile body plan; amniote egg, placenta, and hominid evolution). It includes a bit more on mammalian origins and convergent evolution on separate continents. The sections on human origins, early evolution, and dispersals are updated, as in a new Focus on Science essay.

**UNIT V. PLANT STRUCTURE AND FUNCTION** This unit has major changes. Chapter 25 has new art on meristems, plant tissues, stem and root primary growth patterns, secondary



growth and wood characteristics. Chapter 26 has a more inviting introduction and a new section on soil properties, plant nutrients, leaching, and erosion. Water conservation (e.g., at stomata) follows the section on water transport. A new micrograph of tracheids and an experiment on wilting are included.

Chapter 27 includes a revised section on seed and fruit formation and dispersal, new art on patterns of plant growth and development, and a simple explanation of the difference between growth and development. It has the classic photograph of gibberelin-inspired cabbage plants and new art for experiments on flowering responses.

**UNIT VI. ANIMAL STRUCTURE AND FUNCTION** Chapter 28 is a proven, workable introduction to animal tissues, so we left it alone. The rest of the unit has a stronger systems-integration approach, and now starts with chapters on the nervous, sensory, and endocrine systems (29, 30, 31).

In Chapter 29, neuron structure and functioning are treated first, then invertebrate and vertebrate nervous systems. There is new art on action potential propagation along sheathed neurons and better descriptions of the evolution of the vertebrate nervous system and its functional divisions. The section on the human brain is revised; it now has descriptions of cerebrospinal fluid and the blood-brain barrier. The section on memory is updated. The summary includes a new table on features of the vertebrate brain and spinal cord.

The Chapter 30 introduction employs a python and a bat as lead-ins to the concept of receptor specificity. The chapter includes revised sections on somatic sensations, hearing, balance, and vision; and new sections on sensory pathways and chemical senses.

Chapter 31 has revised text and art on feedback control of adrenal hormones. Chapter 32 uses polar huskies to introduce systems responsible for the body's superficial features, shape, and movements. It has a revised sections on skin, bone, and ATP formation in muscle cells, and a critical thinking question on anabolic steroids. New to Chapter 33 are a simple analogy for flow velocity in a closed system, a diagram of flow distribution of cardiac output, a revised section on blood pressure and its control, and a separate section on capillary function.

Chapter 34 has new art and photographs throughout, a bit more on inflammation's chemical mediators and immunotherapy, and updates on HIV and AIDS. Chapter 35 has new art on gill function and on the evolution of complex lungs, more on vocal cords and speech, and a new section on breathing mechanisms. The section on gas exchange and transport is rewritten. Two of the critical thinking questions deal with deep-sea diving. Chapter 36 has new photographs and new art on intestinal structure, and the BMI formula for estimating weight.

Chapter 38 has a more informative overview of sexual vs. asexual reproduction, revised sections on cleavage, cell differentiation, morphogenesis; and a new section on pattern formation that reflects current research. It has revised sections on the emergence of the vertebrate body plan and on birth, aging, and birth control options.

**UNIT VII. ECOLOGY AND BEHAVIOR** Examples from conservation biology thread through the unit. Chapter 39 has a new essay on sampling population density, updates on human population growth, and age structure diagrams for baby boomers. Chapter 40 has the text on keystone species moved to the section on competition, a bit more on parasitism, new material on restoration ecology, and new sections on exotic and endangered species.

Chapter 41 has new art on the hydrologic, phosphorus, carbon, and nitrogen cycles; and updates on greenhouse gases and global warming. Eutrophication is described in the section on the phosphorus cycle. Critical thinking questions address endangered ecosystems and retreating polar ice shelves. Chapter 42 has a simpler diagram of the atmosphere, new art on climate zones and ocean currents, rain shadows, and biome distribution, and a photograph conveying the vulnerability of coniferous forests to fire. It has more on stream ecosystems and an update on newly discovered mid-ocean biodiversity. A new essay focuses on Rita Colwell's cholera research to reinforce a unifying concept, that the atmosphere, ocean, and land connect in ways that profoundly influence the world of life.

New to Chapter 43 is a look at Wangari Maathai's work on reforestation, a more thoughtful essay on tropical forest destruction, a new map on aquifer depletion, new maps on energy consumption, and an update on Chernobyl's aftermath. Chapter 44 includes refined descriptions of instinctive behavior, learned behavior, and communication signals. Reorganization puts descriptions of the benefits and costs of social groups in separate sections. The section on altruism, the essay on self-sacrificing behavior, and the section on human social behavior are rewritten.

## SUPPLEMENTS

Just inside the cover of instructors' examination copies is a foldout brochure describing the comprehensive package of supplements to this book.

## A COMMUNITY EFFORT

After being responsible for two leading textbooks for more than twenty years, you'd think I would be full of myself. But I still wake up terrified in the middle of the night about possible flaws in some paragraph or diagram, about somehow LETTING DOWN STUDENTS. Given such compulsivity, I would have given up long ago if it were not for the ongoing guidance of my special advisors and contributors. Over the years, they have worked closely with me to evaluate my manuscripts and the reviews from an educational network of more than 2,000 teachers and researchers. On the next two pages, I acknowledge those individuals whose contributions continue to shape our thinking. There is no way to describe their thoughtful assistance. I can only salute their commitment to quality in education.

For this edition, Daniel Fairbanks was far more than advisor for the genetics unit. He wrote the new chapter on recombinant DNA technology and genetic engineering.



Our student readers will benefit from the years of research Dr. Fairbanks conducted while writing his own textbook, *Genetics: The Continuity of Life*. Stephen Wolfe, author of the leading textbook *Molecular and Cellular Biology*, gave line-by-line advice on the biochemistry, genetics, and evolution chapters. Paul Hertz and Tyler Miller carefully checked the evolution and ecology units, and Paul did sketches for the new biogeochemical cycles. The highly respected physiology author Lauralee Sherwood rewrote critical passages in the unit on animals. Ron Hoham remains keeper of the pages on protists, and Eugene Kozloff as keeper of the pages on invertebrates. Nancy Dengler, Richard Falk, John Jackson, and Thomas Rost helped improve the chapters on plants and Elizabeth Moore-Landecker guided us through the fungi. Alan Mann helped update the pages on human evolution. Linda Barham refined and carefully compiled answers for all end-of-chapter Self-Quizzes.

The revision started with evaluations and manuscript reviews from the fourth-edition advisors and contributors listed to the right. Bruce Reid, Michael Renfro, and Robin Tyser were especially helpful with their detailed challenges. Tom Garrison and Mattie Roig also brought out the sun on dark days. David Goodin advised us on structural biology. Lisa Starr has a background in biochemistry and immunological research, and a passion for computers and art. Nearly all of the stunning new art in this edition is her work.

Most errors creep into textbooks during the crunched schedules of production. This edition is remarkably free of them, thanks to the professionalism of Mary Douglas and Gary Head, who worked with me every step of the way on its page-by-page design and production. Gary also designs our covers and creates such photographic gems as Fred-and-Ginger, the streetwise snail (Figure 17.1). Mary also keeps me focused. They are the best of the best, and I can't do books without them.

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## GENERAL ADVISORS/CONTRIBUTORS

JOHN ALCOCK *Arizona State University*  
 AARON BAUER *University of Chicago*  
 ROBERT COLWELL *University of Connecticut*  
 JERRY COYNE *University of Chicago*  
 GEORGE COX *San Diego State University*  
 KATHERINE DENNISTON *Towson State University*  
 DANIEL FAIRBANKS *Brigham Young University*  
 PAUL HERTZ *Barnard College*  
 JOHN JACKSON *North Hennipin Community College*  
 RONALD HOHAM *Colgate University*  
 EUGENE KOZLOFF *University of Washington*  
 ROBERT LAPEN *Central Washington University*  
 WILLIAM PARSON *University of Washington*  
 CLEON ROSS *Colorado State University*  
 LAURALEE SHERWOOD *West Virginia University*  
 STEPHEN WOLFE *University of California, Davis*

## FOURTH-EDITION ADVISORS/CONTRIBUTORS

LINDA BARHAM *Meridian Community College*  
 A. KENT CHRISTIANSEN *University of Michigan*  
 FRED DELCOMYN *University of Illinois, Urbana*  
 NANCY DENGLER *University of California, Davis*  
 CATHY DONALD-WHITNEY *Collin County Community College*  
 RICHARD FALK *University of California, Davis*  
 TOM GARRISON *Orange Coast College*  
 DAVID GOODIN *The Scripps Research Institute*  
 ANN LUMSDEN *Florida State University*  
 ANNE MCNABB *Virginia Polytechnic Institute and State University*  
 ALAN MANN *University of Pennsylvania*  
 G. TYLER MILLER, JR. *Wilmington, North Carolina*  
 ELIZABETH MOORE-LANDECKER *Glassboro State University*  
 ALLISON MORRISON-SHETLER *Georgia State University*  
 DAVID MORTON *Frostburg State University*  
 RICHARD MURPHY *University of Virginia Medical School*  
 DAVID NORRIS *University of Colorado*  
 MICHAEL RENFROE *James Madison University*  
 BRUCE REID *Kean College of New Jersey*  
 DAVID REZNICK *University of California, Riverside*  
 MATTIE ROIG *Broward Community College*  
 THOMAS ROST *University of California, Davis*  
 JUDY SCHNEIDEWENT *Milwaukee Area Technical College*  
 ROGER SLOBODA *Dartmouth College*  
 LISA STARR *San Diego, California*  
 IAN TIZARD *Texas A&M University*  
 ROBIN TYSER *University of Wisconsin, LaCrosse*  
 MARK WEISS *Wayne State University*



## CONTRIBUTORS OF INFLUENTIAL REVIEWS

- ALDRIDGE, DAVID, *North Carolina Agricultural and Technical State University*  
 ARMSTRONG, PETER, *University of California at Davis*  
 BAJER, ANDREW, *University of Oregon*  
 BAKKEN, AIMEE, *University of Washington*  
 BARBOUR, MICHAEL, *University of California, Davis*  
 BARKWORTH, MARY, *Utah State University*  
 BELL, ROBERT A., *University of Wisconsin, Stevens Point*  
 BINKLEY, DAN, *Colorado State University*  
 BLEEKMAN, GEORGE, *American River College*  
 BRENGELMANN, GEORGE, *University of Washington*  
 BRINSON, MARK, *East Carolina University*  
 BROWN, ARTHUR, *University of Arkansas*  
 BUCKNER, VIRGINIA, *Johnson County Community College*  
 CALVIN, CLYDE, *Portland State University*  
 CASE, CHRISTINE, *Skyline College*  
 CASE, TED, *University of California, San Diego*  
 COHEN, AMYBETH, *California State University, Fullerton*  
 COLAVITO, MARY, *Santa Monica College*  
 CONKEY, JIM, *Truckee Meadows Community College*  
 CROWCROFT, PETER, *University of Texas at Austin*  
 DANIELS, JUDY, *Washtenaw Community College*  
 DAVIS, JERRY, *University of Wisconsin, La Crosse*  
 DEMMANS, DANA, *Finger Lakes Community College*  
 DEMPSEY, JEROME, *University of Wisconsin*  
 DENGLE, NANCY, *University of Toronto*  
 DESAIX, JEAN, *University of North Carolina*  
 DETHIER, MEGAN, *University of Washington*  
 DEWALT, R. EDWARD, *Louisiana State University*  
 DIBARTOLOMEIS, SUSAN, *Millersville University of Pennsylvania*  
 DIEHL, FRED, *University of Virginia*  
 DLUZEN, DEAN, *Northeastern Ohio Universities College of Medicine*  
 DOYLE, PATRICK, *Middle Tennessee State University*  
 DUKE, STANLEY H., *University of Wisconsin, Madison*  
 DYER, BETSEY, *Wheaton College*  
 EDLIN, GORDON, *University of Hawaii, Manoa*  
 EDWARDS, JOAN, *Williams College*  
 ELMORE, HAROLD W., *Marshall University*  
 ENDLER, JOHN, *University of California, Santa Barbara*  
 ENGLISH, DARREL, *Northern Arizona University*  
 ERWIN, CINDY, *City College of San Francisco*  
 EWALD, PAUL, *Amherst College*  
 FISHER, DAVID, *University of Hawaii, Manoa*  
 FISHER, DONALD, *Washington State University*  
 FLESSA, KARL, *University of Arizona*  
 FONDACARO, JOSEPH, *Hoechst Marion Roussel, Inc.*  
 FRAILEY, CARL, *Johnson County Community College*  
 FRISBIE, MALCOLM, *Eastern Kentucky University*  
 FROELICH, JEFFREY, *University of New Mexico*  
 FULCHER, THERESA, *Pellissippi State Technical Community College*  
 GAGLIARDI, GRACE S., *Bucks County Community College*  
 GENUTH, SAUL M., *Mt. Sinai Medical Center*  
 GHOLZ, HENRY, *University of Florida*  
 GIBSON, THOMAS, *San Diego State University*  
 GOODMAN, H. MAURICE, *University of Massachusetts Medical School*  
 GOSZ, JAMES, *University of New Mexico*  
 GREGG, KATHERINE, *West Virginia Wesleyan College*  
 HARRIS, JAMES, *Utah Valley Community College*  
 HARTNEY, KRISTINE BEHRENTS, *California State University, Fullerton*  
 HASSAN, ASLAM, *University of Illinois College of Veterinary Medicine*  
 HELGESON, JEAN, *Collin County Community College*  
 HESS, WILFORD M., *Brigham Young University*  
 HUFFMAN, DAVID, *Southwest Texas State University*  
 INGRAHAM, JOHN L., *University of California, Davis*  
 JENSEN, STEVEN, *Southwest Missouri State University*  
 JOHNSON, LEONARD R., *University of Tennessee College of Medicine*  
 JUILLERAT, FLORENCE, *Indiana University, Purdue University*  
 KAREIVA, PETER, *University of Washington*  
 KAUFMAN, JUDY, *Monroe Community College*  
 KAYE, GORDON I., *Albany Medical College*  
 KAYNE, MARLENE, *Trenton State College*  
 KENDRICK, BRYCE, *University of Waterloo*  
 KEYES, JACK L., *Linfield College, Portland Campus*  
 KILLIAN, JOELLA C., *Mary Washington College*  
 KIRKPATRICK, LEE A., *Glendale Community College*  
 KREBS, CHARLES, *University of British Columbia*  
 KREBS, JULIA E., *Francis Marion University*  
 KUTCHAI, HOWARD, *University of Virginia Medical School*  
 LANZA, JANET, *University of Arkansas, Little Rock*  
 LASSITER, WILLIAM, *University of North Carolina*  
 LEVY, MATTHEW, *Mt. Sinai Medical Center*  
 LEWIS, LARRY, *Bradford University*  
 LITTLE, ROBERT, *Medical College of Georgia*  
 LOHMEIER, LYNNE, *Mississippi Gulf Coast Community College*  
 LOPO, ALINA C., *University of California-Los Angeles Medical Center*  
 MACKLIN, MONICA, *Northeastern State University*  
 MANN, ALAN, *University of Pennsylvania*  
 MARTIN, JAMES, *Reynolds Community College*  
 MARTIN, TERRY, *Kishwaukee College*  
 MATSON, RONALD, *Kennesaw State College*  
 MATTHEWS, ROBERT, *University of Georgia*  
 MAXWELL, JOYCE, *California State University, Northridge*  
 MCCLURE, JERRY, *Miami University*  
 MCEWARD, LARRY, *University of Florida*  
 MCKEAN, HEATHER, *Eastern Washington State University*  
 MCKEE, DOROTHY, *Auburn University, Montgomery*  
 McNABB, ANNE, *Virginia Polytechnic Institute & State University*  
 MILLER, TYLER, *St. Andrews Presbyterian College*  
 MOISES, HYLAN C., *University of Michigan Medical School*  
 MORTON, DAVID, *Frostburg State University*  
 MYRES, BRIAN, *Cypress College*  
 NAGARKATTI, PRAKASH, *Virginia Polytechnic Institute & State University*  
 NELSON, RILEY, *University of Texas at Austin*  
 PEARCE, FRANK, *West Valley College*  
 PECHENIK, JAN, *Tufts University*  
 PECK, JAMES H., *University of Arkansas, Little Rock*  
 PERRY, JAMES, *University of Wisconsin, Center-Fox Valley*  
 PETERSON, GARY, *South Dakota State University*  
 PIPERBERG, JOEL, *Millersville University*  
 PLETT, HAROLD, *Fullerton College*  
 REEVE, MARIAN, *Emeritus, Merritt Community College*  
 RICKETT, JOHN, *University of Arkansas, Little Rock*  
 ROBBINS, ROBERT, *National Science Foundation*  
 ROSE, GREIG, *West Valley College*  
 RUIBAL, RODOLFO, *University of California, Riverside*  
 SALISBURY, FRANK, *Utah State University*  
 SCHAPIRO, HARRIET, *San Diego State University*  
 SCHLESINGER, WILLIAM, *Duke University*  
 SCHNERMANN, JURGEN, *University of Michigan School of Medicine*  
 SHEGAL, PREM, *East Carolina University*  
 SHONTZ, NANCY, *Grand Valley State University*  
 SELLERS, LARRY, *Louisiana Tech University*  
 SHOPPER, MARILYN, *Johnson County Community College*  
 SMITH, JERRY, *St. Petersburg Junior College, Clearwater Campus*  
 SMITH, MICHAEL E., *Valdosta State College*  
 SMITH, ROBERT L., *West Virginia University*  
 SOLOMON, NANCY, *Miami University*  
 STEARNS, DONALD, *Rutgers University*  
 STEELE, KELLY P., *Appalachian State University*  
 STEINERT, KATHLEEN, *Bellevue Community College*  
 SUMMERS, GERALD, *University of Missouri*  
 SUNDBERG, MARSHALL D., *Louisiana State University*  
 SWANSON, ROBERT, *North Hennepin Community College*  
 SWEET, SAMUEL, *University of California, Santa Barbara*  
 TAYLOR, JANE, *Northern Virginia Community College*  
 TERHUNE, JERRY, *Jefferson Community College, University of Kentucky*  
 TIZARD, IAN, *Texas A & M University*  
 TROUT, RICHARD E., *Oklahoma City Community College*  
 WAALAND, ROBERT, *University of Washington*  
 WAHLERT, JOHN, *City University of New York, Baruch College*  
 WALSH, BRUCE, *University of Arizona*  
 WARING, RICHARD, *Oregon State University*  
 WARNER, MARGARET R., *Purdue University*  
 WEBB, JACQUELINE F., *Villanova University*  
 WEIGL, ANN, *Winston-Salem State University*  
 WEISS, MARK, *Wayne State University*  
 WELKIE, GEORGE W., *Utah State University*  
 WENDEROTH, MARY PAT, *University of Washington*  
 WHITE, EVELYN, *Alabama State University*  
 WHITENBERG, DAVID, *Southwest Texas State University*  
 WINICUR, SANDRA, *Indiana University, South Bend*  
 YONENAKA, SHANNA, *San Francisco State University*



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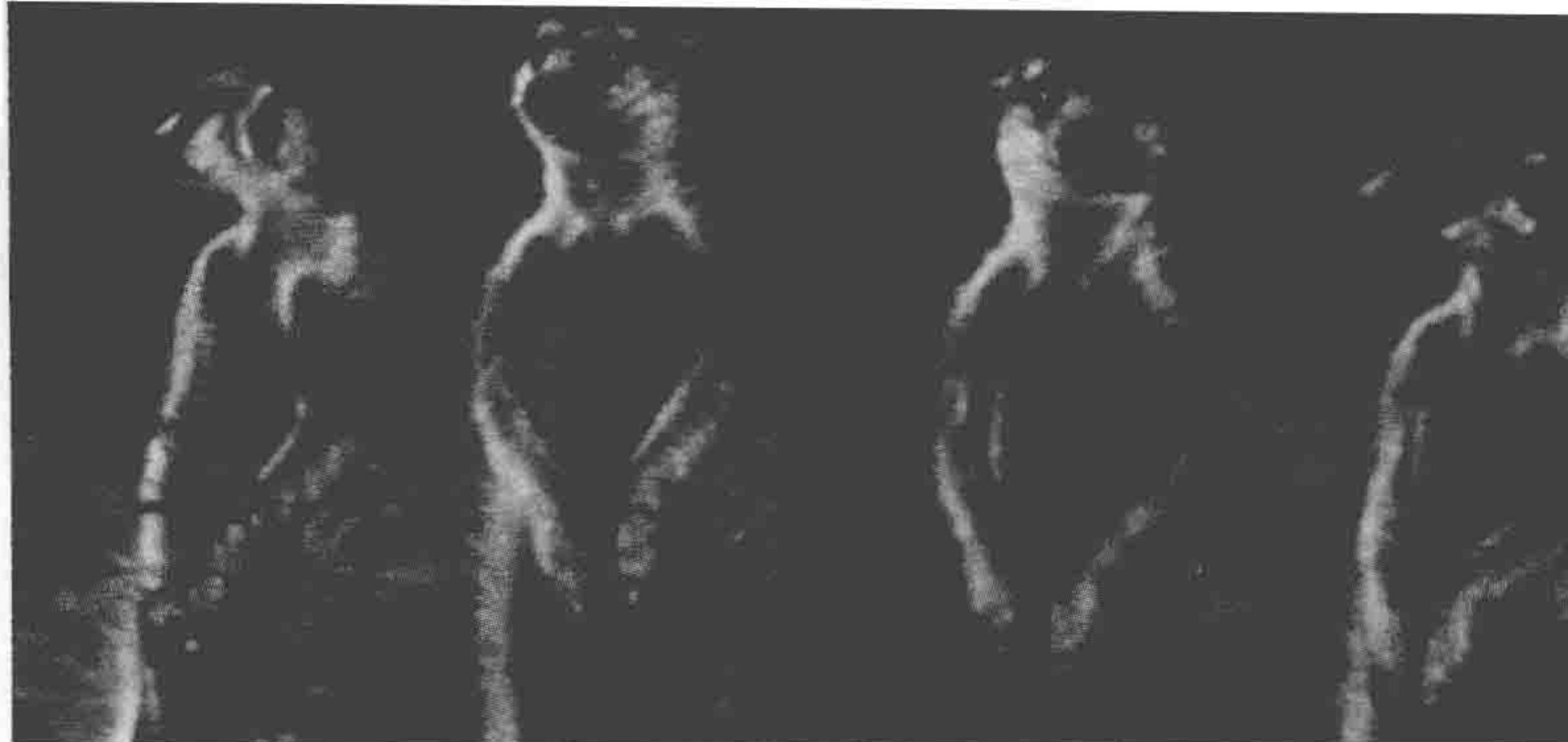
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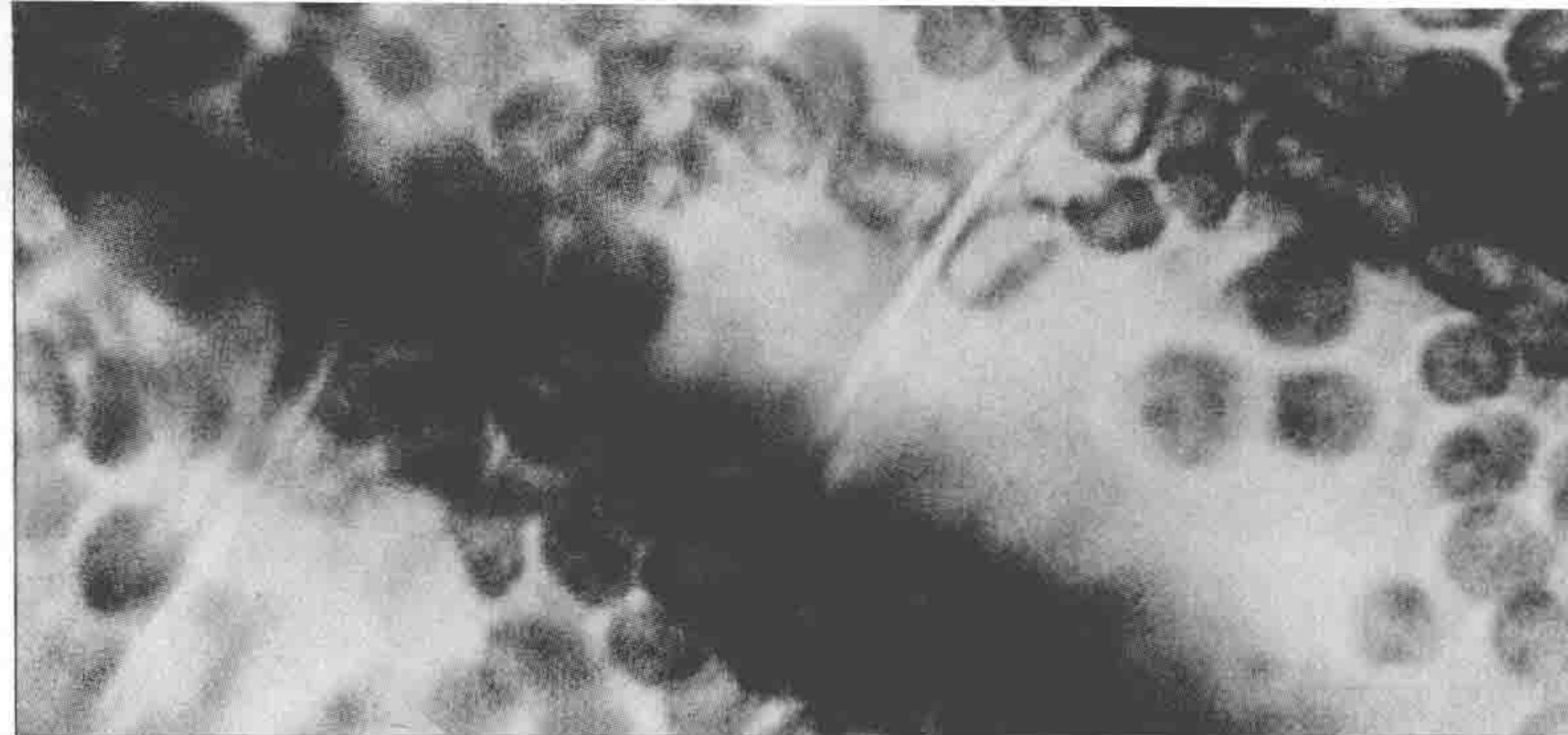
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