THE NATURE OF LIFE

John H. Postlethwait & Janet L. Hopson

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Prologue

Biological issues and ideas have become increasingly important in our society. We read and hear about the ozone layer and skin cancer. The greenhouse effect. The disappearance of rain forests and the rapid loss of our planet's animal and plant diversity. Experimental treatments and vaccines for widespread diseases such as malaria, AIDS, and hepatitis. Debate over the so-called human genome project to unravel the complete genetic code of human beings. Genetic engineering research on drugs to prevent damage from heart attacks. The discovery of hereditary factors underlying heart disease, schizophrenia, and manic depression. Lawsuits regarding surrogate motherhood. Controversy about the use of tissue from stillborn fetuses for research. Identifying criminals by their "genetic fingerprints." Questions about the origin of man. Puzzlement over the causes of the great dinosaur extinctions. Research on chemical communication between trees. The introduction of crops that can thrive without insecticides. The mechanisms of memory. And so on.

The Nature of Life is a wonderful introduction to biology. Every page announces that biology is an exciting intellectual experience. It is clearly and interestingly written and illustrated, easy to teach with, and easy to learn from. The authors chose their subjects thoughtfully, and only selected durable, memorable, and often novel examples. The excitement and the grace of the prose quickly captivate students. And they can readily see how their newly acquired knowledge can be applied. These insights make learning from this book wonderful and new, much to the credit of John Postlethwait and Janet Hopson.

JOHN POSTLETHWAIT is internationally renowned for important research discoveries in developmental biology, insect biology, endocrinology, and the immune systems of invertebrates. In almost all of his experiments, he has used genetics and molecular biology as powerful tools to help him tease answers from nature. He is an editor of two scientific journals and an accomplished writer.

Beyond this, John Postlethwait has taught biology to thousands of college students at the University of Oregon, since joining the faculty in 1971 and culminating in 1982 with the Ersted Award for Distinguished Teaching. He now teaches a general biology course for nonmajors and has taught a similar course for biology majors. He has also pioneered new approaches to biology education. Year after year, John gets rave reviews in student evaluations. His customers like his product! He is complimented for his ability to zero in on key ideas, his ability to relate one piece of knowledge to the next, his clear thinking, and his real love for both biology and teaching. Those talents show in this book.

JANET HOPSON is a marvelously talented science writer whose articles have appeared in the *New York Times Magazine*, *Smithsonian*, *Reader's Digest*, *Psychology Today*, *Rolling Stone*, *Cosmopolitan*, and dozens of other major publications. Her work has also appeared in more than a dozen books, including seven textbooks. Her most recent work is an important new biology text for majors, *Biology*, co-authored by Norman Wessells. She has taught and lectured about writing for more than a decade at the University of California at Berkeley, the University of Missouri, George Washington University, San Francisco State University, and Mills College. She currently lectures on science writing at the University of California at Santa Cruz.

Janet utilizes three special techniques. One is the declarative sentence, which she employs with skill and grace to convey ideas clearly and memorably. The second is the ability to capture and hold the attention of the reader with marvelous examples drawn from an encyclopedic knowledge of biology. The third is the ability to relate the biology she writes about to the world's work—to commerce, archaeology, medicine, agriculture, conservation, behavior, and other subjects. *The Nature of Life* is filled with her exciting ideas and graceful writing.

The book's contributors, all leaders in their fields, lend special authority, currency, and taste to a number of the chapters and have chosen to emphasize what is really important. John Postlethwait and Janet Hopson took these chapters and their own and thoroughly rewrote and revised the combined manuscript to make *The Nature of Life* a well-integrated whole.

In addition to providing the reader with a clear understanding of biology and its pervasive impact on the modern world, this book imparts the generic skills of problem solving and scientific reasoning that students can use throughout their lives. I believe *The Nature of Life* will give its readers a competitive advantage as they continue their varied careers. I am also convinced that mastering this book will dramatically affect the way the reader views the world: The world will have more texture, more connectedness, a certain inner logic; the world will look different. Finally, studying this book will give readers new language skills for interpreting the living world around them in a rewarding way, and for understanding articles in *Time*, *Newsweek*, and other popular media that deal with scientific, environmental, and medical issues.

As a consulting editor, I have contributed to the lively ferment that went into *The Nature of Life*. It has been exciting, and I am pleased with the finished product. I hope that you will enjoy it.

HOWARD A. SCHNEIDERMAN
St. Louis, Missouri
August 1988

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Preface

Introductory biology touches the lives of modern college students in more ways than any other course. The principles and applications of life science encompass proper nutrition, the benefits of aerobic exercise, acid rain, sexual function, disappearing rain forests, genetic engineering, human origins, the threat of AIDS, innovative medical treatments, new crops for a hungry planet, and dozens of other important topics.

The student of biology can interpret the issues of health, energy, environment, agriculture, and medicine facing our society with new understanding and clarity. He or she can also appreciate the complexity and beauty of the natural world much as the student of music appreciation can better enjoy classical music. Biology educators agree that after the professor's interpretive lectures and personal instruction, the right textbook is the biology student's most important tool. With this in mind, we set out to design and write a book that would be the ultimate learning tool—one that could help students master basic biological concepts, understand the issues of personal and societal concern, and appreciate the natural world as no similar book has done before.

■ **OUR APPROACH** Most introductory biology textbooks present roughly the same material. It was our view, however, that the books differ radically in how well they capture and hold the student's imagination and interest, and in how well they help the reader sort through the welter of new terms, facts, and principles in this field. We set as our highest priorities reader motivation and orientation and clear explanation of concepts. We believe that the organization and visual impact of each chapter reflect that approach.

Each chapter begins with a story—an example from the natural world meant to draw in the reader and illustrate the central questions addressed in that segment of the book. Chapter 25, for example, tells the story of the kangaroo rat, a remarkable rodent that can survive the drought and heat of the desert without drinking water. The obvious question is *How?* and the answer unfolds as the chapter explores the functioning of animal excretory systems—in particular, the mammalian kidneys—and their role in water and salt balance.

In addition to a central natural history example, each chapter's two-page introduction maps out the major questions addressed in the chapter, the order in which topics appear, and three or four unifying themes that recur throughout the chapter and that tie the material to the broader concerns of the section and the book.

The introduction is aimed at both motivating and orienting students, so they can see immediate applications for the chapter's material, as well as the inherent order of topics. Although students necessarily encounter complex and sometimes strange new ideas during their study of biology, we want the visitors to this novel territory to be equipped with street maps, road signs, and compasses. If a reader must repeatedly puzzle out how one topic relates to the next, how the two are related to the chapter subject, and how that material fits into the science of life as well as into their own lives, then a textbook has failed. We believe our readers will always know where they are in this book, where they are headed, and why.

Our approach to student motivation and orientation includes three unifying themes that occur throughout the entire book:

- Living things take in *energy* to maintain their internal order and organization.
- Living things undergo *reproduction* so that the species continues after the individual ceases to exist.
- Specialized means of acquiring energy and characteristic patterns of reproduction arise. These innovations allow living organisms to adapt to changing environments.

These themes not only provide a general context for many biological facts and principles, but they also help the student interpret and appreciate specific organisms and their adaptations. For example, a fuchsia plant growing on a dry slope in southern Oregon has hairy green leaves. These assist in trapping the sun's energy, which the plant must collect, convert, and use in order to maintain its internal body organization. In late summer, the fuchsia produces brilliant red trumpet-shaped flowers that store nectar and form seeds—structures involved in the reproduction of new fuchsia plants. Historically, those plants with showy flowers and rich supplies of nectar have been more likely to attract brilliantly feathered Anna's hummingbirds, which inadvertently aid in the fuchsia's pollination and production of new seeds. Thus the sweet red flowers evolved and are now commonplace adaptations, easy to see on a summer hike in Oregon.

Our design for the book also reflects a special philosophy about illustrations. Biology is a material science, and visualizing the central biological structures and processes is the key to understanding them. A biology professor nearly always lectures with chalk in hand, or a videotape, film, slide series, or acetate ready to display. We wanted our readers to be able to verbalize and visualize concepts simultaneously, so we coordinated our art program as closely as possible with the text through numerous references to figure parts and steps. If used as intended, this book should be the next best thing to a private tutor!

Finally, we created a series of specific features for each chapter to assist our goals of motivation, orientation, and visualization. The book has five kinds of boxed essays to show relevant applications of biology. There are also Close-Up figures to provide additional information for students with exceptional curiosity about biology. Many of the text illustrations have icons to help the student orient structures and processes in space. And there are underlined take-home messages, Connections (end-of-chapter essays integrating concepts), Highlights in Review, Key Terms, Study Questions, and Further Readings to help the student study and learn biology. Pages xxviii–xxxi provide a guided tour of these features in a typical chapter.

■ CONTENTS *The Nature of Life* takes a hierarchical approach to the study of biology. After Chapter 1 introduces the three main themes of the book, we consider how molecules (Chapter 2), cells (Chapter 3), and cellular activities (Chapter 4) provide the common groundwork for life. We end Part I with a clear analysis of how cells obtain and use energy (Chapters 5 and 6), the book's first theme.

From this cellular foundation, we move on to the principles of reproduction, the book's second theme. Chapters 7 through 10 discuss how cells and organisms pass on to their offspring the hereditary units that cause "like to beget like." A short, very up-to-date chapter on the excitement of biotechnology and recombinant DNA techniques (Chapter 11) leads into the fascinating subject of human genetics (Chapter 12). This part of the book ends with an analysis of how egg cells decode instructions stored in DNA to build a fish, fly, frog, or person (Chapters 13 and 14).

With a thorough knowledge of the cellular and genetic features that unify life as background, we survey the diverse range of life forms in Part III. We take an evolutionary approach (our third theme) to the questions of life's origins (Chapter 15). Then we examine the characteristics of organisms from each kingdom of life (Chapters 16 through 19), ending with an in-depth discussion of the human species' own evolutionary descent.

The next two parts of the book investigate how plants and animals maintain their bodies against the inevitable disorganization that occurs over time, a reprise of our first theme. Chapter 20 orients students by presenting the themes that will recur throughout the study of anatomy and physiology. Chapters 21 through 29 analyze individual physiological systems in animals and include dozens of examples that we hope will captivate readers and allow them to understand the biological bases for their own body functions. The series includes a complete discussion of the immune system (Chapter 22), an in-depth treatment of the nervous system, brain, and behavior (Chapters 27 and 28), and a unique chapter on exercise physiology (Chapter 29), which shows how body systems work together as a dynamic whole. This chapter promises to have great appeal for physically active college students.

In Part V, *The Nature of Life* builds on the discussion of plant diversity from Chapter 17 with chapters on plant structure (Chapter 30), the regulation of plant growth (Chapter 31), and plant function (Chapter 32). These chapters incorporate the many new applications of genetic engineering to plant science and emphasize the importance of plants to students' everyday lives.

The next part of the book returns to our evolutionary theme, devoting Chapter 33 to the science of evolution and Chapters 34 through 37 to ecology—how organisms interact with each other and the world around them. We give special emphasis to the ecological and environmental issues that affect our current quality of life and that of future generations.

The book ends with the engrossing subject of behavior (Chapter 38), viewed from evolutionary and ecological perspectives. We believe this is a fitting conclusion, because human behavior will shape the world of the future—a world our students must prepare to lead as professionals and to help preserve as responsible citizens.

We spent nearly eight years producing the first edition of this book, and followed a procedure similar to the one that Norman Wessells and Janet Hopson used to generate *Biology* (Random House, 1988). We researched and created an outline for the book. We wrote first drafts for more than half of the chapters, while experts in various subdisciplines wrote drafts of the remainder. We then carefully rewrote all the material to provide a single student-friendly voice, a coherent presentation, and to incorporate the suggestions of our large panel of reviewers at various institutions and with various subject specialties. At the same time, we met over a series of tables—art tables, light tables, dining room tables—to create the art program, piece by piece. This, too, we revised heavily with help from subject reviewers.

We hope that the end product appropriately reflects both our years of effort and our mutual love of biology. We also hope that it inspires you to learn more about the nature of life and to take an active future role in guarding your own health and fitness, in shaping society's response to the many biological issues we face, and in conserving our world's precious natural resources.

Acknowledgments

This book was truly a team effort, and we are grateful to the unstinting effort of all our colleagues.

Our sponsoring editor, Eirik Børve, guided us through the highs and lows of this long project with energy, creativity, and patience. He gave us the latitude to try out our new ideas and novel procedures, and we are extremely grateful for that freedom and trust, as well as for his sound advice based on years of experience in publishing.

Our consulting editor, Howard Schneiderman, provided invaluable counsel, enthusiasm, support, and high-quality written contributions.

Our formal contributors (listed on the title page) gave the book much of its scientific soundness and point of view. More than 60 reviewers (listed on page xxvii) helped shape our content and presentation in important ways.

Developmental editor Ruth Veres crafted smooth, organized chapters from our often unruly manuscript with dedication, skill, and scientific curiosity. The co-author of a book on immunology, she also contributed the excellent manuscript for Chapter 22.

Developmental art consultant Peter Veres helped design many figures, which—with good humor and occasional whimsy—effectively convey information to a beginning student.

Our copyeditor, Janet Greenblatt, brought her considerable talents to smoothing the manuscript and coordinating a million loose ends.

Several writers, including Dan Adams, Maurice Bleifeld, Jenny Dushek, Jeff Fox, Beverly Fraknoi, Debbie Franklin, and Julie Ann Miller, worked on drafts of the manuscript and contributed creative ideas. Beverly Fraknoi also edited the useful study guides and manuals that accompany this book.

Project manager, designer, and cover designer Hal Lockwood gave the book its handsome appearance and shepherded it through the long and difficult production process with the able help and supervision of Jamie Brooks, Pattie Myers, and Karen Judd. A host of talented scientific illustrators (listed on the copyright page) made creative contributions to the look and effectiveness of our figures.

Photo researcher Stuart Kenter located hundreds of beautiful slides. Many scientists, photographers, and artists gave permission for their work to appear in these pages, and we gratefully acknowledge their individual contributions on pages C-1–C-5.

Nita Postlethwait provided research and technical support throughout the project. Michael Rogers lent computer advice and assistance. Chelle Cumberland-Sims, Lesley Walsh, and Betty Smith assisted us in numerous ways.

Finally we want to thank each other for the personal commitment, dedication, and belief it took to see this project through. If this book succeeds in motivating students to learn the principles of biology, it will be because Jan asked time and again, "Why does an introductory student need to know this?" And if the book succeeds in teaching students those principles in a memorable way, it will be because John answered, time and again, "Well, you see, this is how I explain it to my students . . ."

JOHN H. POSTLETHWAIT and JANET L. HOPSON
August 1988

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A GUIDED TOUR TO *THE NATURE OF LIFE*

Central Example

A narrative about an organism or phenomenon from the natural world to capture interest and to show how the material in the chapter can address a real-world problem.

CHAPTER 8

Mendelian Genetics

White Tigers and Family Pedigrees

In the dry season of 1951, hunters found four tiger cubs playing in the hunting preserve of the Maharajah of Rewa, in central India. Although the hunters were looking for bigger game, one of the cubs caused great excitement: Instead of the normal orange-and-black-striped coat, it had a pure white pelt! Lured into a cage by a bowl of water, the young tiger was brought to the maharajah's palace and named Mohan, meaning "Enchanter." Mohan grew into a magnificent creature, larger than most tigers, strong, and healthy. But he lacked the usual rich orange and jet black pigments of normal tigers; his coat was nearly pure white, with ashen gray stripes. What's more, his nose and paw pads were pink instead of black, and his eyes were ice blue with a tendency to cross (Figure 8.1).

Was Mohan just a fluke of nature, a unique occurrence? Or were his special traits *hereditary*, that is, capable of being passed to offspring and through them to future generations?

Mohan was mated with Begum, a normal tiger, but the results were disappointing: None of the cubs had Mohan's sparkling white coat, and it seemed that Mohan was a once-only occurrence, never to be repeated. But Mohan was kept in a cage with one of his daughters, Radha, and you can imagine the surprise of his keepers when they saw the offspring from an incestuous mating of the two, represented in the family tree in Figure 8.2. Some of the cubs in the second generation had beautiful white coats. To the maharajah's joy, the trait *was* hereditary. Although it appeared to skip Radha's generation, it remained intact (though hidden) and reappeared in the next generation. What could cause a hereditary trait to behave in this hit-and-skip fashion? And what was the relationship of the white pelt to the crossed blue eyes?

Figure 8.1 A White Tiger with Blue Eyes That Tend to Cross.

We will explore the answers to these questions as we investigate **heredity**, the transmission of physical, biochemical, and behavioral traits from parent to child. Observable traits, such as fur and eye color, are controlled by units called **genes**, which are specific, discrete portions of the DNA molecule in a chromosome; and the rules of heredity describe how genes and the traits they determine move from generation to generation. Simple and straightforward, the rules follow directly from the process of meiosis, the special cell division that occurs during the formation of eggs and sperm; and they hold in principle for all sexually reproducing organisms, from the single-celled *Paramecium* to peas and tigers.

Knowledge of genetics also helps reveal the workings of evolution by natural selection. The measured lengths of DNA we call genes are passed along intact from parent to offspring. Genes that underlie an unfavorable trait (such as crossed eyes in a predator like the tiger, which relies on split-second coordination to fell a swift-

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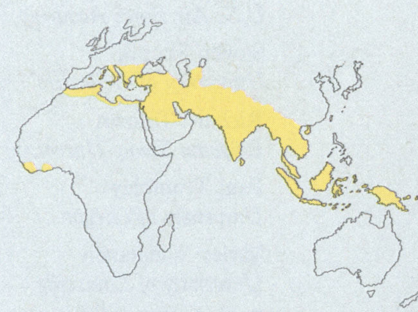

Figure 10.2 Cooley's Disease: A Plague of Equatorial Countries. The yellow-colored zone shows the global regions where thalassemia is currently a major health problem.

gene? The answers to these questions are crucial to the health of children around the world and are based on the principles of gene action discussed in this chapter.

We know that each gene controls the synthesis of one polypeptide (see Chapter 9), so it is not surprising that a disease like thalassemia—the result of a single defective gene—results from errors in the synthesis of a single protein. In thalassemia, the protein is *hemoglobin*, the iron-containing protein in red blood cells that helps carry oxygen from the lungs to tissue cells all over the body. Recall that hemoglobin consists of four polypeptide chains: two α-globin chains and two β-globin chains (see Figure 2.33). People with thalassemia cannot make one or the other of these two kinds of chains and therefore cannot make a complete hemoglobin molecule. β-thalassemia, the inability to synthesize β chains, is the more serious form of the disease.

Four unifying themes will emerge as we follow the processes by which a mutation in a single gene results in a defective protein and ultimately in a range of defects in the individual organism. First is the importance of *base pairing* to protein synthesis. Chapter 9 discussed how important base pairing is to the maintenance of double-stranded DNA and to the precise replication of DNA's information content. But base pairing also allows the cell to translate genetic information into functional proteins. A second unifying theme is that protein synthesis requires a large expenditure of energy, and cells have evolved ways to minimize that energy cost by regulating *gene expression*—the translation of genetic information into proteins. A third theme is that basic genetic mechanisms are essentially universal: All creatures, from bacteria to field mice to flowering dogwood, share the same approach to protein synthesis. A final theme is that despite their fundamental differences in cell size and complexity, prokaryotes and eukaryotes regulate the expression of their genes in similar ways.

The chapter will answer several important questions:

- How do genes work to control protein shape and function, and ultimately, the activities of living things?
- How does information flow from DNA to RNA to proteins?
- How can even slight alterations in DNA lead to diseases like thalassemia?
- How is gene activity in prokaryotes and eukaryotes regulated, and how does this regulation determine when and where the information in a gene will be used?
- What causes many adults to become ill after consuming large amounts of milk or ice cream?
- How can a simple test that employs common bacteria reveal whether a chemical might cause cancer in humans?
- Why do some people get skin cancer from a single day in the sun?

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Unifying Themes

Three or four thematic statements that tie the chapter concepts to each other, to the part, and to the book as a whole.

Advance Organizer

A list of the chapter's specific objectives, framed as:

- the general biological question probed;
- the major topics considered, in sequence; and
- two or three "teasers" or fun questions to stimulate curiosity about the chapter.

and seed dispersal. These innovations occurred along with other adaptations for life on land, such as broad leaves for efficient solar collection, and enabled the angiosperms to radiate into more species than the combined numbers of all other plant groups.

Today, flowering plants are the most common and conspicuous species in the earth's tropical and temperate regions, and from this monumentally successful group come virtually all of our crop plants (wheat, rice, corn, soybeans, fruits, and vegetables) and beverages (coffee, tea, colas, and fermented drinks), as well as spices, cloth, medicines, hardwoods, ornamental plantings, and, of course, flowers—symbols of beauty, affection, and renewal throughout human history. Table 17.2 shows the two major subclasses of the angiosperms, the **monocots** and the **dicots**, and their main characteristics.

Angiosperm Reproduction: A Key to Their Success

As in gymnosperms, the angiosperm life cycle displays the complete dominance of the diploid (sporophyte) generation and the complete dependence of the haploid (gametophyte) generation on the conspicuous adult plant. The word *angiosperm* means "seed in a vessel," and indeed, seed development takes place within a structure at the base of the flower, called the *ovary*, which gives the ovules much more protection than the gymnosperm cone scale. The wall of the ovary eventually matures into a fruit that surrounds the seeds and aids in dispersal. In some cases, animals attracted to the fruit's colorful skin or luscious flavor eat the fruit and then excrete the seeds along with feces in some new location. Plants have myriad dispersal mechanisms, including loft "parachutes" that loft the seed in the wind, hooks for hitchhiking on passersby, and tasty fruits.

The ovary is just part of the female reproductive structure (carpel) within the flower. A sticky top, or **stigma**, and a slender neck, or **style**, lead to the ovary, and inside the ovary are one or more ovules containing megaspore mother cells. The male flower part is the *stamen*, made up of the **anther**, a club-shaped structure that houses microspore mother cells, and the *filament*, a slender stalk. The mother cells give rise via meiosis to immature male gametophytes, or pollen grains. A ring of colorful petals surrounded by a ring of often small green sepals completes the flower.

In spring, when the flowers of a given species open, the megaspore mother cells inside the ovary give rise, via meiosis, to four megaspores (Figure 17.25, step 1). Normally, three of these degenerate (step 2) and one divides into the female gametophyte, including one egg cell (step 3).

(a)

(b)

(c)

Figure 17.24 How Plants Disperse Seeds. (a) Butterfly weed seeds, *Asclepias tuperosa*, blowing in a summer breeze. (b) Prickly seed of the common burdock, *Artimum munus*, clinging to a terrier's face. (c) Cedar waxwing feeding berries to its young.

Underlined Take-Home Messages

Passages that present or summarize key concepts are underlined in blue to aid review.

Boxed Essays

Short discussions of interesting experiments, new research findings, and relevant applications of biological concepts. The five kinds of boxes include Personal Impact, Historical Perspective, How Do We Know?, How Does It Work?, and In the News.

BOX 8.1 HISTORICAL PERSPECTIVE

Mendel and His Mentors

Without the help of a supportive family and insightful teachers, Gregor Mendel (Figure B8.1) might never have left the family farm. The son of a prosperous farmer in what is now Czechoslovakia, Mendel spent many of his early years learning the finer methods of flower and fruit tree cultivation, as well as the art of beekeeping. Nature fascinated the child, as did science and mathematics, and a teacher at the local elementary school recognized Mendel's exceptional talent and urged his parents to continue his education. They consented, but ran into trouble midway through his secondary schooling, when his invalid father developed financial problems and could no longer manage the farm or Gregor's schooling. An older sister, Veronika, took over the farm, and a younger sister, Theresia, gave Gregor part of her dowry to continue his studies.

In the fall of 1843, Cyril Napp, a broad-minded abbot who required his postulants to pursue secular as well as religious education, accepted Mendel into the Augustinian order at a very special monastery in old Brno. There Mendel came into contact with many of the prominent philosophers and scholars of the time as he developed his own "interdisciplinary major," combining studies of agriculture and winegrowing with theology and philosophy. While substitute teaching mathematics, Latin, German, and Greek at a local high school as part of his parish responsibilities, Mendel was so successful that the school administrators sent him to the University of Vienna to take a qualifying exam to become a certified teacher of natural history and physics.

Mendel flunked the examination. Two times. But Abbot Napp continued to support him through two years of study at the university. Ill health took Mendel back to the monastery, where he continued his teaching and became known as a schoolmaster who was much more pleased with a pupil's lively interest in a subject than with a mind full of memorized facts.

This tenacity in challenging orthodox thought stood the monk in good stead once he began to link his loves of nature and mathematics through the careful study of the reproductive behavior of pea plants. Ten years of intensive research yielded his now-famous principles of heredity, but the world wasn't ready to listen. At two public lectures of the Natural Science Society in Brno in 1865, biologists of the day listened politely as Mendel outlined his results and theories, and then they quietly ignored the work for 35 years. The theories were essentially mathematical, and at that time mathematicians and plant breeders worked in completely different realms.

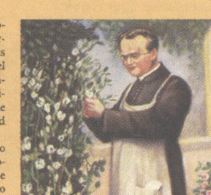

Figure B8.1 Gregor Mendel with His Beloved Pea Plants.

Disappointed, Mendel returned to the monastery and eventually became abbot, trading most of his scientific studies for the administrative tasks of running a busy abbey. But the study of biology would never be the same. The farmer's son who saw a connection between the worlds of mathematics and agriculture had introduced quantitative analysis to a new field, and geneticists today are still reaping the results.

summer, when the pods became swollen with plump peas, he collected the seeds. These seeds would produce the next generation, called the **first filial (F_1) generation**, meaning the first generation in the line of descent. Planted in the spring of the second year, the F_1 seeds of the long-stem/short-stem cross all grew into long-stem plants (Figure 8.6a). The characteristic that appears in the F_1 hybrid, such as long stems in peas or orange color in tigers, is said to be **dominant**, while the one that does not appear (short stems or white fur) is referred to as **recessive.**

What happens to the recessive characteristic? Does it disappear completely? Does it blend with the dominant characteristic? Or does it remain intact but hidden in the F_1 generation? Although he would have to wait a year to find out, Mendel knew exactly how to learn the answers to these questions. He allowed the long-stem F_1 hybrid plants to self-fertilize, and the next spring he planted the seeds of the **second filial (F_2) generation**. When the second generation of pea plants grew up, most of them had long stems, but significantly, there were some plants with short stems. Again, no stems of intermediate length appeared (Figure 8.6a). The reappearance of pure short stems among the offspring of long-stem hybrids was dramatic disproof of the blending theory and concrete evidence for the particulate theory of heredity.

Segregation Principle for Alleles of One Gene

Mendel was not satisfied with saying that "some" of the F_2 plants had short stems. He counted the number and found that 787 of the F_2 plants had long stems, while 277 had short stems. These numbers showed about a 3:1 ratio (2.84:1) of long-stem to short-stem plants in the F_2 generation. When Mendel examined monohybrid crosses for all seven traits,

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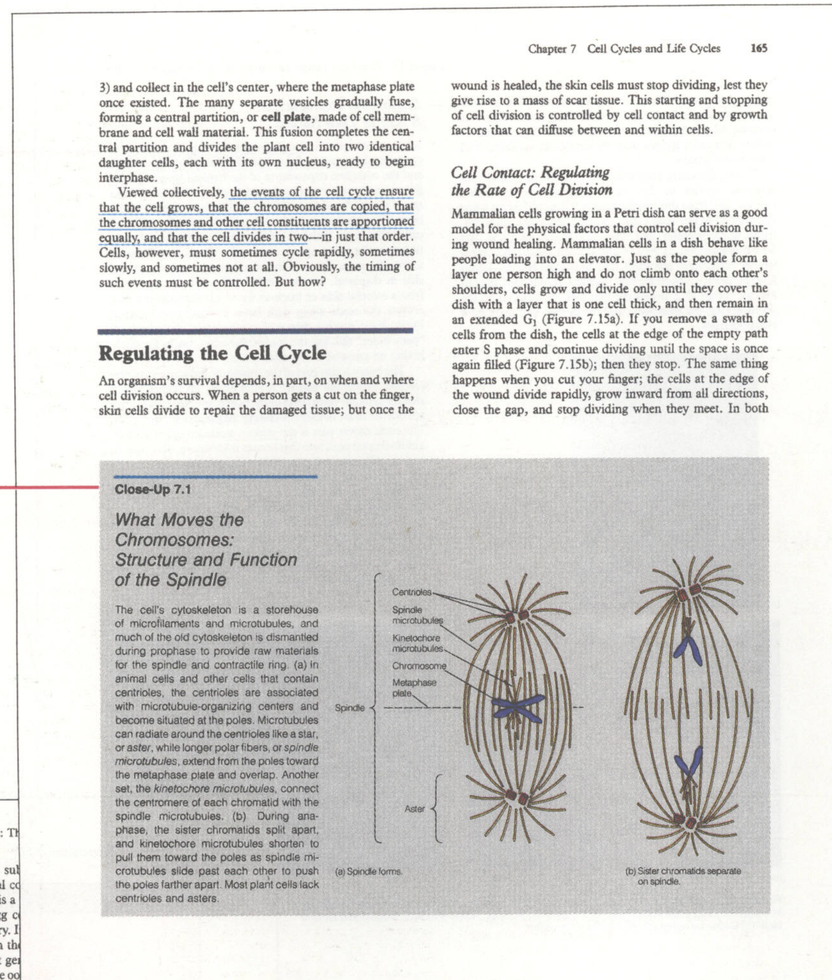
Close-Up Figures

Enrichment figures and explanatory text for the curious student. These allow flexibility in level of detail so the book can be appropriate for either biology nonmajors or majors.



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3) and collect in the cell's center, where the metaphase plate once existed. The many separate vesicles gradually fuse, forming a central partition, or **cell plate,** made of cell membrane and cell wall material. This fusion completes the central partition and divides the plant cell into two identical daughter cells, each with its own nucleus, ready to begin interphase.

Viewed collectively, the events of the cell cycle ensure that the cell grows, that the chromosomes are copied, that the chromosomes and other cell constituents are apportioned equally, and that the cell divides in two—in just that order. Cells, however, must sometimes cycle rapidly, sometimes slowly, and sometimes not at all. Obviously, the timing of such events must be controlled. But how?

Regulating the Cell Cycle

An organism's survival depends, in part, on when and where cell division occurs. When a person gets a cut on the finger, skin cells divide to repair the damaged tissue; but once the wound is healed, the skin cells must stop dividing, lest they give rise to a mass of scar tissue. This starting and stopping of cell division is controlled by cell contact and by growth factors that can diffuse between and within cells.

Cell Contact: Regulating the Rate of Cell Division

Mammalian cells growing in a Petri dish can serve as a good model for the physical factors that control cell division during wound healing. Mammalian cells in a dish behave like people loading into an elevator. Just as the people form a layer one person high and do not climb onto each other's shoulders, cells grow and divide only until they cover the dish with a layer that is one cell thick, and then remain in an extended G_1 (Figure 7.15a). If you remove a swath of cells from the dish, the cells at the edge of the empty path enter S phase and continue dividing until the space is once again filled (Figure 7.15b); then they stop. The same thing happens when you cut your finger; the cells at the edge of the wound divide rapidly, grow inward from all directions, close the gap, and stop dividing when they meet. In both

Close-Up 7.1

What Moves the Chromosomes: Structure and Function of the Spindle

The cell's cytoskeleton is a storehouse of microfilaments and microtubules, and much of the old cytoskeleton is dismantled during prophase to provide raw materials for the spindle and contractile ring. (a) In animal cells and other cells that contain centrioles, the centrioles are associated with microtubule-organizing centers and become situated at the poles. Microtubules can radiate around the centrioles like a star, or *aster*, while longer polar fibers, or *spindle microtubules*, extend from the poles toward the metaphase plate and overlap. Another set, the *kinetochore microtubules*, connect the centromere of each chromatid with the spindle microtubules. (b) During anaphase, the sister chromatids split apart, and kinetochore microtubules shorten to pull them toward the poles as spindle microtubules slide past each other to push the poles farther apart. Most plant cells lack centrioles and asters.

(a) Spindle forms.

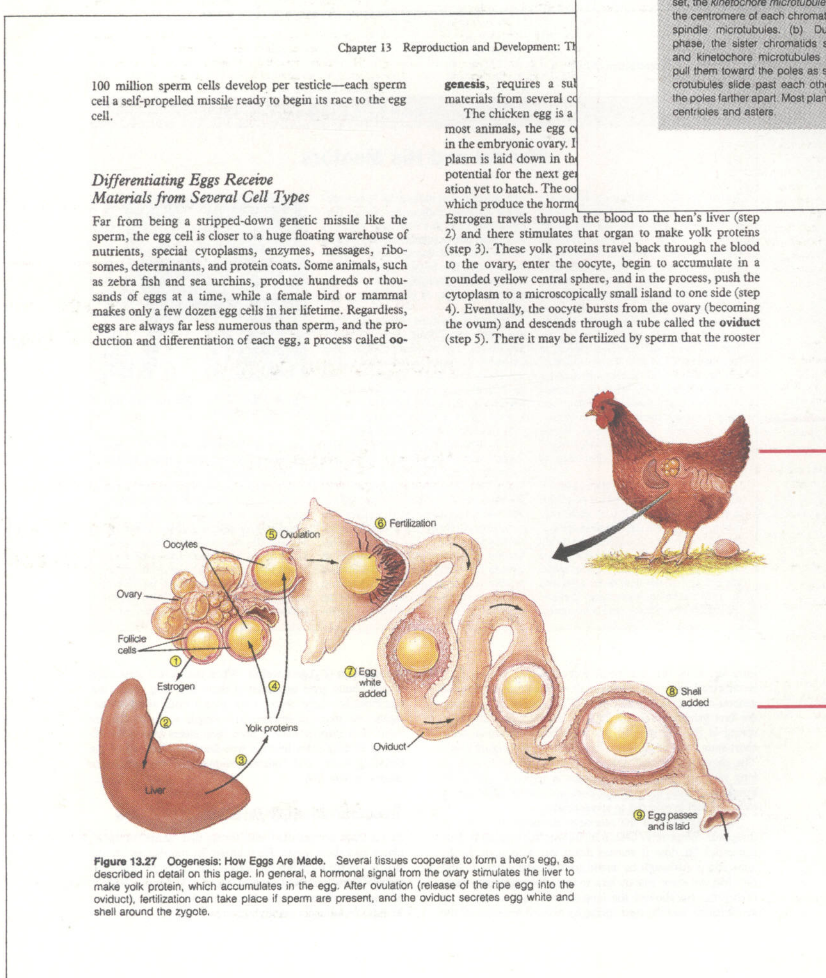
(b) Sister chromatids separate on spindle.

Extensive Use of Icons

Small diagrams of cells or organisms to help orient the student to the physical location of the structure or process shown in the figure.

Extensive Use of Process Diagrams

Figures that depict sequential biological events with individual steps numbered and keyed to step-by-step discussions in the text or figure legend.



Chapter 13 Reproduction and Development: Th

100 million sperm cells develop per testicle—each sperm cell a self-propelled missile ready to begin its race to the egg cell.

Differentiating Eggs Receive Materials from Several Cell Types

Far from being a stripped-down genetic missile like the sperm, the egg cell is closer to a huge floating warehouse of nutrients, special cytoplasms, enzymes, messages, ribosomes, determinants, and protein coats. Some animals, such as zebra fish and sea urchins, produce hundreds or thousands of eggs at a time, while a female bird or mammal makes only a few dozen egg cells in her lifetime. Regardless, eggs are always far less numerous than sperm, and the production and differentiation of each egg, a process called **oogenesis**, requires a sub materials from several c

The chicken egg is a most animals, the egg c in the embryonic ovary. I plasm is laid down in th potential for the next ge ation yet to hatch. The oo which produce the horm Estrogen travels through the blood to the hen's liver (step 2) and there stimulates that organ to make yolk proteins (step 3). These yolk proteins travel back through the blood to the ovary, enter the oocyte, begin to accumulate in a rounded yellow central sphere, and in the process, push the cytoplasm to a microscopically small island to one side (step 4). Eventually, the oocyte bursts from the ovary (becoming the ovum) and descends through a tube called the **oviduct** (step 5). There it may be fertilized by sperm that the rooster

Figure 13.27 Oogenesis: How Eggs Are Made. Several tissues cooperate to form a hen's egg, as described in detail on this page. In general, a hormonal signal from the ovary stimulates the liver to make yolk protein, which accumulates in the egg. After ovulation (release of the ripe egg into the oviduct), fertilization can take place if sperm are present, and the oviduct secretes egg white and shell around the zygote.

Connections

A short essay that integrates key themes, concepts, and applications and that ties the ideas of the current chapter to those of the next.

Highlights in Review

A point-by-point recap of the chapter's main points to aid review.

that flanks the β-globin gene. Regulatory sequences of DNA flanking eukaryotic genes act much like the promotors and operators in prokaryotic operons. Most eukaryotic genes, for example, have the sequences TATA and CCAAT (called the "TATA box" and the "Cat box") in front of the gene's first exon as an indicator of where transcription should begin. In some thalassemia victims, a mutation in the TATA box prevents the β-globin gene from being transcribed. Other regulatory signals called *enhancers* exist, but we are only just beginning to learn what they are and how they regulate gene expression.

Connections

Let us reflect on what the principles of transcription, translation, and gene regulation mean for a child suffering from β-thalassemia. The child is a helpless spectator in the race between its bones, which are making red cells as fast as possible, and its spleen, which is destroying red cells just as fast. The starting gun in this macabre marathon can be a single base-pair substitution anywhere along the β-globin gene. In some mutations, the gene isn't fully transcribed or isn't even transcribed at all; in others, the intron is not excised and no mRNA is made. Or translation may be blocked prematurely. Each mutation provokes the same result: Little or no β-globin is formed, so the red cells are distorted by clumps of α-globin and destroyed by the spleen.

Hope comes from the β-globin multigene family. If physicians could somehow block the normal turning off of the globin genes expressed in the fetus, then the red cells could make complete fetal hemoglobin molecules. Fetal hemoglobin would work perfectly well in the individual's blood: Even as the child grew to adulthood, red cells with fetal hemoglobin would not be destroyed by the spleen, so no anemia would develop, and the thalassemia would disappear.

Perhaps if geneticists understood the two-step mechanism of eukaryotic gene regulation in as much detail as they do the lactose operon in *E. coli*, they could use some yet-to-be identified gene activator of fetal globin genes to cause children to continue to synthesize fetal hemoglobin. Nevertheless, since Watson and Crick's work in the 1950s, geneticists have learned a tremendous amount about the structure of DNA and how genes are built, regulated, and occasionally mutated. One of the most remarkable episodes in scientific history began in the late 1970s when biologists, using this knowledge, learned to manipulate genes. This ability led to a revolution in biological engineering that is still going on and is the subject of Chapter 11.

Highlights in Review

1. Genes work by specifying the base sequence of mRNA, which specifies the amino acid sequence of a polypeptide. DNA makes RNA through a process called transcription, and RNA makes protein through a process called translation.
2. Messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA) differ from DNA in that they consist of ribonucleotides rather than deoxyribonucleotides. A single oxygen atom on the sugar ribose differentiates the two kinds of nucleotides. RNA consists of only a single strand of nucleotides, not a double strand, as in DNA; and the RNA base uracil replaces the DNA base thymine. RNA molecules are also much shorter than DNA molecules because they tend to code for only one or a few genes rather than for the whole genome.
3. Like replication, transcription is directed by base pairing and
enzyme. But in transcription,
the deoxyribonucleotide bases
zyme is RNA polymerase rather
g transcription, a few genes may
, while during replication, the
once. The newly formed RNA
A molecule in transcription, in-
a newly replicated DNA strand.
4. The genetic code, transfer RNA, and ribosomes together bring about translation. The genetic code is identical in nearly all organisms. A group of three bases is a codon. Except for the start codon and the three stop codons (which tell RNA polymerase where to begin and end transcription), each codon specifies one amino acid. Several different codons may specify the same amino acid, but no codon specifies more than one amino acid.
5. The tRNAs translate the mRNA codons into an amino acid sequence. At one end of each tRNA molecule is an anticodon; at the other end is a specific amino acid. The anticodon pairs up with the mRNA codon so that the amino acids are ordered according to the mRNA codon sequence.
6. Ribosomes hold mRNAs, tRNAs, and amino acids in place until the amino acids can be joined together into a polypeptide. Each mRNA may have several ribosomes running along it at once, all translating polypeptides off the same mRNA.
7. A change in the base sequence, a mutation, may consist of a base substitution, insertion, deletion, or rearrangement. Usually, DNA repair enzymes detect and fix altered DNA; if these enzymes fail, a permanent mutation occurs. A change in the sequence of DNA bases results in a change in the sequence of RNA bases, which results in a change in the sequence of amino acids—an altered polypeptide.

bring about the cyclic production and release of eggs (the menstrual cycle).

7. The corpus luteum produces estrogen and progesterone and promotes the buildup of the uterine lining (endometrium). If an egg is fertilized, this lining is maintained throughout pregnancy. If the egg is not fertilized, the corpus luteum degenerates, and the lining is sloughed off.
8. Sexual attraction and intercourse can bring about a convergence of egg and sperm in the female's oviduct, followed by fertilization, the fusion of one sperm nucleus with the egg nucleus.
9. Birth control, or contraception, relies on techniques for blocking fertilization; techniques for preventing implantation; or techniques for preventing embryonic growth.
10. To overcome infertility, a man or woman may need hormone-like drugs, corrective surgery, in vitro fertilization, artificial insemination with donor gametes, or the help of a surrogate mother.
11. Pregnancy is a partnership between embryo and mother. After the embryo implants in the uterine lining, it develops a chorion, and this produces a hormone, hCG, that prevents the corpus luteum from degenerating and hence the lining from being sloughed off. Pregnancy tests detect hCG levels in the urine. The chorion grows and enmeshes with maternal tissue to form the placenta, which nourishes the embryo, removes wastes, and screens out bacteria and toxins.
12. The human embryo develops much as do other mammalian embryos. It produces an amniotic sac; undergoes gastrulation, neurulation, and organogenesis; and grows rapidly during gestation.
13. Sexual differentiation in the fetus begins with an indifferent embryo that is neither male nor female. In the absence of a biochemical signal, the gonads, sex ducts, and external genitalia develop as female structures. If a *Y* chromosome is present, the indifferent gonads becomes testes, the organs produce testosterone and Mullerian inhibiting hormone, and male ducts and external genitalia develop.
14. The mother's nutrition, life-style habits, and taking of prescription drugs can affect fetal development.
15. The fetus programs itself and its mother for delivery. Among other changes, it stores special fat and carbohydrate reserves, secretes hormones that prepare the mother's breasts for milk production, and cause her body to release the signals (prostaglandins and oxytocin) that initiate labor and delivery.
16. Infancy and childhood are periods of phenomenal physical growth and mental development, including the acquisition of language. Puberty is marked by an additional growth spurt and by the maturation of sexual organs and the development of secondary sexual characteristics. During adulthood, the body reaches its peak physical performance, then gradually declines until senescence sets in and the body ages more rapidly.
17. Aging may be caused by genetic programming, by wear and tear, or by other factors. Regardless, it is possible to age gracefully, particularly by observing good health habits throughout life.

Key Terms

cervix, page 312
chorion, page 317
endometrium, page 312
epididymis, page 308
follicle, page 311
in vitro fertilization, page 306
life expectancy, page 327
life span, page 327
menstrual cycle, page 312
ovary, page 311
ovulation, page 312
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prostate gland, page 308
scrotum, page 308
semen, page 309
seminal vesicle, page 308
seminiferous tubule, page 308
senescence, page 326
testis, page 308
testosterone, page 310
urethra, page 309
uterus, page 312
vagina, page 312
vas deferens, page 308

Study Questions

Review What You Have Learned

1. List the following structures in their proper order to show the route sperm travel from their place of origin to the outside world: epididymis, vas deferens, seminiferous tubules, prostate gland, ejaculatory duct, and urethra.
2. Create a chart of male hormones using the following headings: Name of Hormone; Where Formed; Effect.
3. Outline the feedback loop that maintains the sperm supply.
4. Where is an egg produced? What pathway does the egg follow from site of production to the outside world?
5. Create a chart of female hormones using the following headings: Name of Hormone; Where Formed; Effect.
6. Of the 400 million human sperm released during coitus, how many will fertilize the egg? Explain.
7. What are some causes of infertility in women? In men?
8. Why is the chorion important to the developing embryo?
9. Is it true that an embryo's blood mixes with its mother's in the placenta? Explain.
10. How does the *Y* chromosome stimulate male differentiation?

Apply What You Have Learned

1. Why might a pregnant woman suffer a miscarriage if her body does not produce enough progesterone?
2. Researchers have isolated a gene on chromosome 21 that may be responsible for Alzheimer's disease. What is the practical value of this finding?

For Further Reading

FALKNER, F., and J. M. TANNER, eds. *Human Growth: A Comprehensive Treatise*, 2d ed. Vol. 1. *Developmental Biology and Prenatal Growth*. Vol. 2. *Post-Natal Growth and Neurobiology*. New York: Plenum Press, 1986.

KEETON, K., and Y. BASKIN: "Birthtech." *Omni* 8 (December 1985): 91–98. *Essentials of Human Embryology*. Toronto: B.C. Decker, 1988.

MOORE, K. L. *Before We Are Born: Basic Embryology and Birth Defects*, 2d ed. Philadelphia: W. B. Saunders, 1983.

Key Terms

A list of the chapter's boldface vocabulary terms with a page number for easy reference and review.

Study Questions

Short-answer and essay questions to aid in reviewing the chapter's main facts and ideas.

For Further Reading

Up-to-date references for reading beyond the text material.

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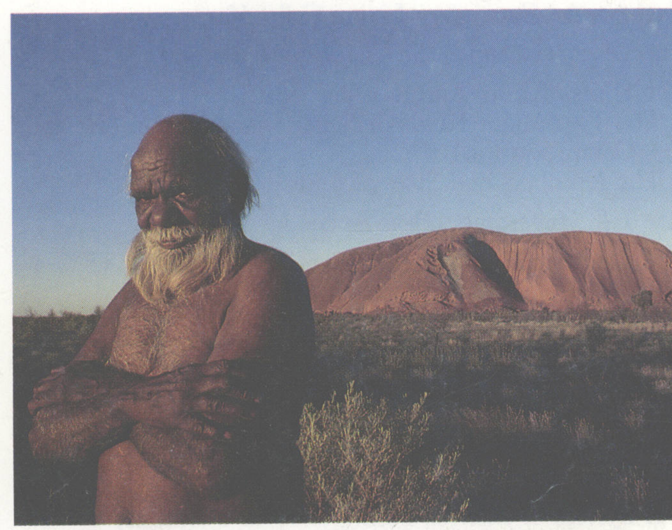

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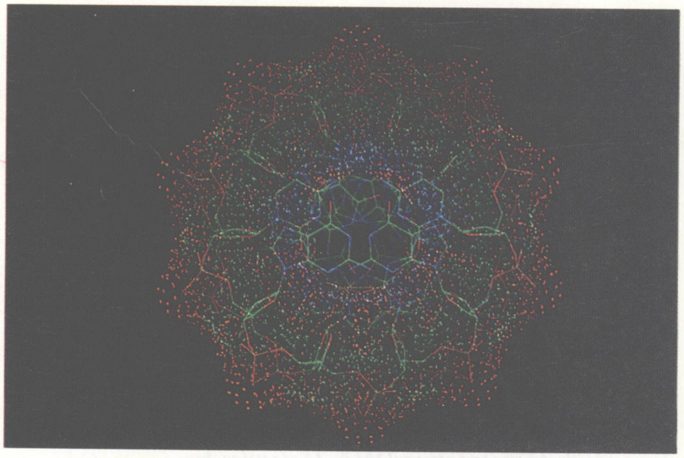

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