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UNDERSTANDING BIOLOGY

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Page 939 constitutes a continuation of the copyright page.

Preface

The purpose of this book, as its title suggests, is to show beginning students that biology is basically simple, coherent, and easy to understand. It has not always been so. During the past couple of decades, the science of biology has undergone a revolution that has transformed it from a collection of loosely related facts into a modern science. This is good news for students. It is good news because loosely related facts, important as they are individually, are difficult to comprehend without the coherence of the modern viewpoint that is now possible in biology. *Understanding Biology* recognizes this revolution, takes advantage of, and, indeed, exploits it on behalf of the student and on behalf of biology itself. That is, this textbook is more than a potpourri, or a collection of facts about genetics, cell structure, ecology, metabolism, DNA, RNA, protein, evolution, and the physiology of plants and animals. (Is it any wonder that students have found biology courses based on the standard, formless model so difficult?)

But before explaining what we have done differently, we hasten to say that this book contains the same general range of facts found in comparable books. These facts are needed to create the comprehensive view of biological phenomena that is taught in most courses. The difference is in the way we organize and relate these facts. In some chapters, especially those that deal with the physiology of plants and animals, we include a wider range of interesting phenomena than is common in books of this kind, in order to show the splendor of living organisms and to tell some of the many fascinating stories about them. But we can talk about many of the specifics in those later chapters without confusing the student because we have first laid the necessary groundwork by developing a series of broad, comprehensive principles that make sense of these specifics. The major concepts are emphasized throughout the text with the titles "law" and "principle" in boldface type; and we have always tried to keep the forest in sight while showing some of its trees by summarizing the points of the discussion with statements in italics. (Similarly, material that is optional because it is either slightly more difficult or somewhat tangential to the discussion is pointed out by an asterisk preceding the section number.)

The single most important concept of this book is the recognition that biological systems are fundamentally *genetic systems:* structures that inherit genetic information, that occasionally undergo mutations, and that are therefore capable of evolving. This is *not* a singular, narrow view of biology that somehow excludes all other views. The ecological, the biochemical, the cytological, and the many other possible viewpoints all find their place in this picture, but none is where we begin conceptually. For instance, some physicists and chemists have tried—none of them successfully, as far as we know—to understand organisms in terms of a complex theory of the thermodynamics of open systems. Whether organisms might eventually be understood in this way or not, one must ask how such a thermodynamic system ever came into existence. The only answer proposed so far is that it evolved into that state by virtue of its genetic properties and those of its ancestors.

Biology has come of age. It is a mature science, one that has outgrown parochial disputes over "The Truth" as viewed by partisans of genetics or ecology or molecular biology or physiology. It is practically impossible to draw lines that define these fields now, and we have not tried to do so. Only by crossing traditional lines—by ignoring them, in fact—have we been able to create a sensible organization for the science. Given the genetic conception of an organism, the rest of biology falls into place, as we will show in the following overview of the book's organization.

All beginnings are hard. Chapter 1 eases the reader into the subject by considering some central questions about the nature of knowledge in general and of science in particular. It lays special emphasis on the hypothetical structure of knowledge, including perception itself, and on the concept of a scientific paradigm. This leads into an outline of the major ideas of the modern paradigm of biology.

The phenomenon of evolution through Darwinian mechanisms begins to emerge from the definition of an organism in Chapter 3, but the phenomenon itself is first discussed in Chapter 2. The concept of evolution has long been a major principle of biology which imposes great order and comprehensibility on the science. Chapter 2 explores some of the variability among organisms in terms of evolution and as a factor that creates evolution.

In Chapter 3 we get to the basics of our subject. Here we show that organsims are cellular, that they reproduce themselves, and that growth and reproduction depend upon the operation of a genome that carries genetic information. We present a useful model for understanding the operation of a genetic system (a self-reproducing automaton), and we also show that the great bugaboo of biology—the apparent purposefulness of life—can be understood rather simply as a consequence of the genetic nature of organisms.

With this foundation, information transfer in the cell becomes a central theme that organizes all of metabolism—the chemical activities of organisms. But before exploring that theme (in Chapters 7 through 9), we need to develop a background. Chapter 4 discusses the basic chemical structure of organisms and introduces a major point that helps make biology easy for students who know very little chemistry: that organic molecules need to be understood primarily as specific *shapes* that can bond to one another in various ways. We also show how important it is that organisms are built of huge molecules (polymers) that are strings of smaller molecules (monomers).

Chapter 5 introduces some concepts about energy and outlines the basic ideas about metabolism in the context of the ecosystem—the world of organisms that eat one another and share a living space. We show how the flow of matter and energy in a cell is just a part of this flow through the whole ecosystem, and this provides a second broad and realistic context for understanding metabolism.

The structural, energetic, and genetic foundations for metabolism are brought together in Chapter 6, where we show, first, that the whole object of metabolism is to create monomers that can be made into biological structure and, second, that this happens through metabolic pathways that are like assembly lines, so an organism is like a factory that continually makes more of itself. But we also introduce a new unifying concept in biology called parataxis, which has to do with the way small molecules (ligands) fit into cavities in large molecules (proteins) and thus change the shape of the proteins so they perform important functions. This one idea serves to make sense out of an enormous number of biological phenomena. We show how important it is that many ligands are just distinctively shaped molecules used as signals to carry information from one place to another.

Chapters 7 and 8 are relatively straightforward discussions of the major processes in metabolism. The major way we help the reader make sense of this metabolism is by showing the central role of a cycle of reactions, the Krebs cycle, around which many chemical transformations revolve. In Chapter 9 we get down to the specifics of how the genetic system operates. The details of the interaction between DNA, RNA, and protein are relatively easy to understand now, since we have already outlined the general process. We also point out here how the process of information transfer in cells (from nucleic acid to protein, not the reverse) determines the mechanism of evolution.

Chapter 10 is a broad overview intended to place the whole matter of growth, development, and reproduction into the context of time and cycles. We discuss organisms as creatures of time and outline the cycle of cell growth and reproduction and then the sexual cycle, a series of events that most organisms go through as they grow and reproduce.

Chapters 11 and 12 outline some of the specifics of cellular structure and organization. We did not simply devote one earlier chapter to a discussion of "the cell," as most books do, because the entire discussion of metabolism was placed in a cellular context. But even in these chapters we do not simply pile up details that are unnecessary at this level. We are still seeking general unifying ideas. We show how there is information in the very structure of an organism—not just in its genome—so as an organism grows, a structure can create greater structure like itself. We also show how the transport of molecules across membranes can be understood rather easily in terms of the action of proteins. Many cellular processes are unified around a few central structures (microtubules and microfilaments) and the flow of material in protein synthesis.

Part 2 focuses on the operation of the genetic system and the matter of development. We show the importance of genetic analysis, a new way of thought and experimentation in biology that has been used to dissect and understand the intricate operations of organisms. Chapters 13 and 14 reveal the power of this method and the major insights derived from it. Chapter 15 discusses the patterns of inheritance seen in sexual organisms like us. Then in Chapters 16 and 17 we explore some aspects of growth and development, based on the genetic foundations developed earlier.

Part 3 begins with Chapter 18, which provides another overview, this time on the general nature of plants and animals, organs and tissues, and some aspects of the biology of large organisms that depend upon surface-volume and mass-area relationships. Chapters 19 and 20 are devoted to the biology of plants, focusing first on some aspects of their growth and transport mechanisms and then on the major growth regulators and on phenomena that are regulated by light. Since we believe it is best to use plant reproduction as a major theme for telling the story of plant evolution, that discussion is reserved for Chapter 36.

The heart of animal physiology is covered in Chapters 21, 22, and 23. We begin by outlining the major mechanisms of regulation, the nervous and endocrine systems, emphasizing their close relationship and basic similarities. Chapter 22 then discusses circulation, respiration, and excretion in a unified manner. We have put these three topics into a single chapter so we can discuss the various points in a logical order. Such a discussion is impossible under the traditional approach, which segregates each topic into its own chapter even though they are not separated functionally. Chapter 23 then takes up some aspects of digestion, nutrition, and the utilization of nutrients.

Chapter 24 discusses the often ignored matter of infection and the inflammatory and immune systems designed to combat it. Here we achieve a unified view of these complex processes. Chapters 25 through 27 are devoted to the nervous system and its sensory and motor activities, and this provides a background for Chapters 28 through 30, which concern animal behavior, including sexual behavior and the physiology of reproduction.

Part 4 (Chapters 31 through 34) comprises a discussion of ecology and the mechanisms of evolution. We treat these topics together because it is simply impossible to separate them realistically. We emphasize that the ecosystem and community constitute the theater within which the drama of evolution takes place. Chapter 31 explores the physical structure of the ecosystem; Chapter 32 describes the structure of populations, both their genetics and their growth dynamics; Chapter 33 shows some aspects of community structure; and Chapter 34 takes up certain aspects of evolution in more detail.

Part 5 is a survey of the major groups of organisms, again in an evolutionary context. Chapter 35 covers the origin of biological systems and major lines of evolution in simple organisms. Chapter 36 discusses the fungal and plant kingdoms, using the evolution of reproduction as a major theme, while Chapter 37 surveys the animals. This brings us to human evolution, the subject of Chapter 38 and the concluding topic of the book.

The purpose of this organizational scheme is to make coherent sense of biology by unifying the science around a few major themes. Both modern psychology and the experience of thoughtful teachers agree that people can only really learn those things that are logically connected to one another to make a sensible picture. Isolated bits of information are quickly lost from the memory. Psychology and educational experience also show that people learn best by doing rather than by just listening and reading; no matter what form new ideas are presented in, each person must play with those ideas actively and work them over for himself or herself into a coherent form. We have tried to help the reader do this by presenting a number of exercises to work on (with answers in the back of the book); they are not used in every chapter, but we use them particularly for those topics that can only be grasped by applying the concepts in the text to practical problems. We urge the use of these exercises in studying.

One problem with biology is that it uses an enormous vocabulary; a large share of the words in a standard dictionary comes from biology. The necessary words are all included here, but we wish to emphasize that, for the most part, terminology is quite unimportant, so we have selected a short list of words, emphasized in boldface type, that the reader *must* become familiar with. Students will probably have to learn many other words—those that are simply italicized in the text—but the relative importance of these will be determined by the instructor.

Chemistry makes many students nervous, and mathematics can be positively terrifying. So we have tried to use as little chemistry and physics as possible. Moreover, we keep everything that readers need to know about these subjects in a biological context, and we emphasize that the oddly shaped organic molecules that appear throughout the book are primarily just differently shaped blocks. The only real mathematics we demand is the ability to handle exponential notation, and this is explained in the Appendix (as is the metric system).

As you read this book, you may be able to detect the delight, the fascination, and the excitement that the biological world holds for us. Our hope is that you will come to share these feelings as you begin to understand that world.

Two people don't write a book of this complexity by themselves. We owe a special debt to our friend John Painter for his great help and support in developing the book and to our editor, Bill Bryden, for his faith, support, and hard work on our behalf. We extend our thanks to the staff of Harcourt Brace Jovanovich with whom we have had a delightful collaboration: to Barbara Rose for intelligent and painstaking editing; to André Spencer for copy editing and traffic management; to Geri Davis for beautiful design work; to Sue Lasbury for art supervision and photo researching; to Fran Wager for production supervision; and to Michelle Pinney for editorial assistance. In the end, we depended on modern wordprocessing systems, and for their help in computing we thank the Computer Services staff at Evergreen State College, particularly Chuck Blanchard and Chas Douglass; Bill Barrett of Willavon, Inc.; and Mimi Hiller of The Muse Co.

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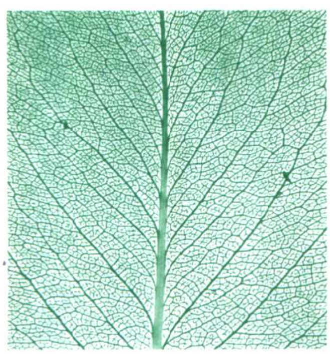
Contents

PART

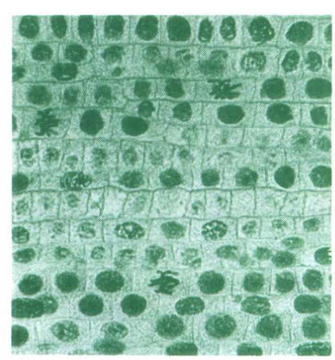
1

Foundations of Biology



PART 2

Heredity and Development



PART 3

The Biology of Plants and Animals