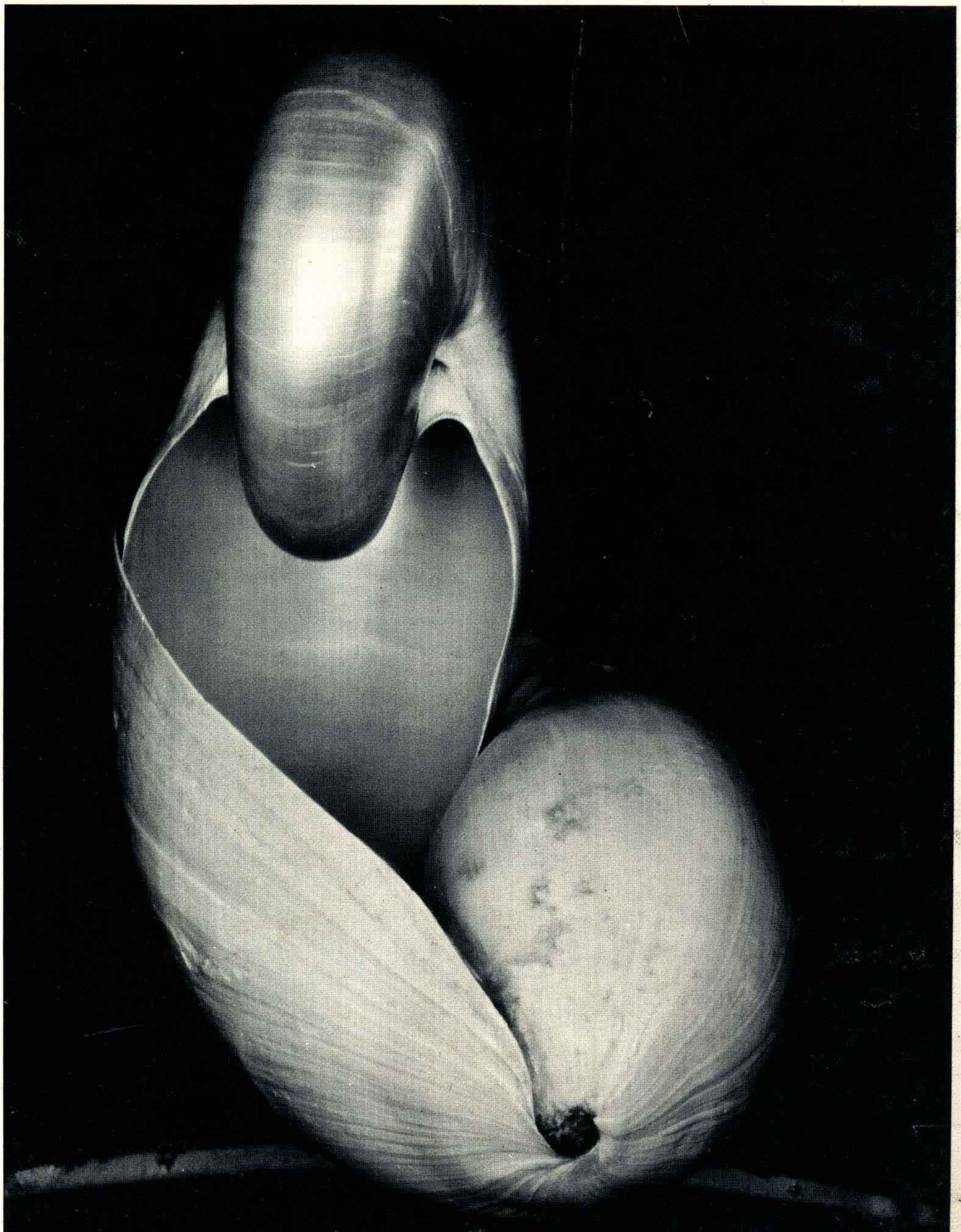
Elements of BIOLOGY



PREFACE

THIS text is designed for one-term introductory biology courses at the college level. It is a systematic treatment of living things—their characteristics, the problems they face, and the concepts that biologists have discovered in learning to understand them. The text includes practical applications of biological knowledge and treats current biological issues where appropriate. It attempts to lead the student to a better understanding of himself and his environment, and to provide a reference that will serve him well, both as a student and as an interested person in a time of major biological discovery.

The text presents biology as a dynamic discipline, continually incorporating new research and posing, as well as answering, new questions. The approach is inclusive, for to limit an introductory book to a particular school of biological thought (be it ecological, molecular, phylogenetic, or whatever) is sometimes to sacrifice the broad understanding that is the object of the introductory course. In the lecture, of course, different approaches will be developed in response to the professor's expertise and his students' interests. The textbook provides a broad perspective against which special interests and future developments may be viewed.

The Plan of the Book

This text begins with the chemical basis of life and ends with living organisms placed in the contexts of time, through evolution, and space, through ecology. In between the functioning of the cell and the organism are treated in lively detail, with some emphasis on human biology.

The Study of Life, the introductory chapter, develops important biological concepts—specifically the characteristics of life, the meaning of evolution, and the methods of scientific research. The diverse subject matter of biology is suggested here and, later, in a special color portfolio that deals with careers and subdisciplines in biology.

Part I: The Fundamentals of Life opens with a step-by-step explanation of those chemical and physical principles that are essential to an understanding of life. The structures and life processes of cells are then discussed in such a way as to give the student a sense of the challenges faced by all organisms. Special attention has been paid to providing a clear and accurate account of the processes students find difficult: photosynthesis and respiration.

Part II: Structure and Function of the Organism gives comprehensive coverage to the physiological processes that sustain life: nutrition, internal transport and gas exchange, homeostasis, chemical control, nervous control, and movement. Each chapter considers the process as it appears both in plants and animals. The part closes with behavioral patterns that supplement the physiological responses to the challenges of maintaining life.

Part III: The Continuity of Life presents principles and ideas about the ways in which organisms reproduce and transmit genetic material. After a preview of reproductive processes in plants and animals, mitosis and meoisis are introduced and utilized in a discussion of Mendelian genetics and its modern applications. The chapter on molecular genetics explains the mechanism of genetic expression, with special emphasis on protein synthesis and cellular control. The chapter on development shows applications of this material. A color portfolio, focusing on the reproductive structures primarily of the flowering plants, supplements Part III and supports laboratory work in this area.

Part IV: Organisms and Their Environment surveys the diversity of organisms and shows how they are classified. Evolution emerges as the dominant theme of the chapter that follows. The different kinds of environments, and man's impact on them, are studied in the final chapters on biomes and ecology. A color portfolio on biomes gives visual impact to this material.

SEQUENCING

The foregoing plan takes the student through the different levels of functional organization of living systems. Each part of the text forms an integral unit, organized around a central theme. However, the ordering of the parts and the sequencing of chapters may be altered at the professor's discretion. Five common sequences, which reflect other course syllabuses, are shown here, but others may occur to the professor as he develops his approach to the introductory course.

Functional emphasis
Part 1
Part 2
Part 3
Part 4

Phylogenetic emphasis
Part 1
Chapter 16
Part 2
Part 3
Chapters 17, 18, 19

Biochemical-genetic emphasis
Part 1
Part 3
Part 2
Part 4

Evolutionary emphasis
Chapter 1
Chapters 17, 16
Part 1
Part 2
Part 3
Chapters 18, 19

Ecological emphasis
Chapter 1
Chapters 18, 19
Part 1
Part 2
Part 3
Chapters 16, 17

Why Another Biology Text?

The complaint most frequently made about introductory textbooks is that they are not readable—that it is difficult to learn from them. A first step in producing this book, therefore, was to define readability as it applied to biological material. With much thought, and with the assistance of professionals, we decided that a readable biology text is a text that organizes material clearly, in a teachable sequence; a text that draws upon a wealth of biological detail and yet elucidates general principles and themes; a text that selects examples and experimental data with regard for both scientific importance and probable interest value; and a text that conveys some of the excitement of biology through graphics, without skimping or overwhelming the text itself. In addition, we found that the manner in which concepts and terms are introduced is critical: a successful biology text will introduce terms and concepts with full explanation and concrete examples of their use. The student will not be made to feel that he must learn a whole new vocabulary before he can approach the material.

PEDAGOGICAL AIDS

Illustrations Many of the subtleties of biological structures and processes can be portrayed especially well through visual images; in fact, a good graphical treatment can reinforce a textual description and render it more memorable. This book contains a large number of photographs, photomicrographs, and line drawings, captioned in detail. Because photographs and line drawings represent different images of an organ or organisms, we have sometimes used both techniques to portray a given subject.

Tables and Graphs Empirical evidence is easiest for the student to grasp if it is summarized visually in a way that is clear and attractive. We have used tables and graphs both to summarize material explained in the text and to present detailed data of a reference nature. For example, after explaining the general characteristics of hormones, and detailing the more important ones, we have included a reference table that describes those hormones not treated separately. Aids such as these can help the student extend his knowledge from general to particular instances.

Summaries and Glossary An end-of-chapter summary reviews the major principles of each chapter and redefines essential terms. A glossary of nearly 600 major terms is also provided at the end of the text.

Readings Many teachers suggest outside reading to enrich the learning experience. Each chapter of this text includes a selective annotated bibliography of books and articles. Some of these are classic studies of a biological topic; others treat very current research. Works by writers in fields related to biology—in psychology and anthropology, for example—are included where appropriate. And, due to the growing relevancy of biological issues to all segments of the population, it is possible in many areas to list works that are written in a more popular vein.

Supplements Accompanying the text are a Study Guide and Workbook, a Laboratory Manual, and Instructor's Manual, and a Test Item File. The Workbook is designed to help students interrelate concepts from various sections and chapters and to review the important points of the text. For each chapter of the text, the Workbook includes a review outline, questions for study and discussion, and application questions relating biology to the student's own concerns.

The Instructor's Manual includes not only an overview of each text chapter, but also suggested resources for discussion and topics for research projects. Suggestions for essay questions are also given. Approximately 1000 multiple choice questions are separately available on cards in the convenient Test Item File.

Acknowledgments

I would like to extend my appreciation to several institutions that helped shape my career: To the U.S. National Park Service which inspired my enthusiasm as a lab scientist by providing me with experience as a park ranger naturalist; to the Fulbright Committee, which provided me a year-long unique experience in Kenya, East Africa, that helped so much in restoring my appreciation of the grandeur of nature; to the U.S. Atomic Energy Commission, the National Aeronautics and Space Administration, the National Science Foundation, and the National Cancer Institute, all of which provided me with opportunities to explore new facets of biology and to broaden my scope as a scientist.

The number of colleagues and friends who have contributed in a variety of ways is endless, but I would like to single out for special appreciation Ira Bowers Hansen, who taught me how to organize and present material in a systematic and stimulating way, to the late Henry Quastler of Brookhaven National Laboratories for opening up a true appreciation for the excitement of research, and special thanks to Bert Berlin for his yeoman work, particularly in the botanical sciences. Without his efforts this work might still be in the editor's to-be-completed file.

C. K. L.

PART I

THE FUNDAMENTALS OF LIFE

PART II

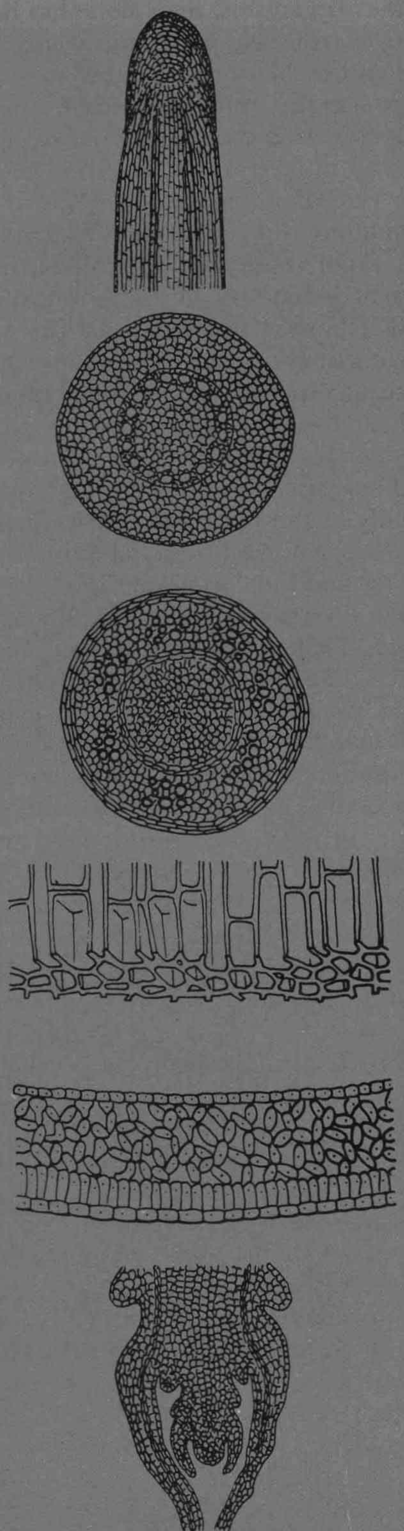
STRUCTURE AND FUNCTION OF THE ORGANISM

PART III

THE CONTINUITY OF LIFE

PART IV

ORGANISMS AND THEIR ENVIRONMENT



Part I

THE FUNDAMENTALS OF LIFE

1 THE STUDY OF LIFE

AMONG all other organisms, man alone has had the ability to arise from the Earth and transport himself to the threshold of the solar system to look back, both literally and scientifically, upon the site of his origin. Man the scientist has plotted his beginnings over unimaginable periods of time: He knows that $4\frac{1}{2}$ billion years ago the Earth, a molten rock spinning through space, began to cool; that water vapor condensed and rained, and that the incessant pounding of water on rock washed minerals from the stones, so that the waters ran in rivers, into great depressions that formed the oceans. In the ocean, living things gradually originated—a few odd molecules, with the properties that we call living, were formed. These living chemicals changed; slowly at first, then more rapidly as the living substances themselves changed the earth. And from the substances that some have termed the "primeval slime" there eventually arose a diversity of plants and animals, and also an erect, facile, manipulative, and very curious creature—man. In time, man evolved to the point that he has been able to travel to a companion world in search of other living things.

Man's exploration of outer space, however, is simply a spectacular climax—a curtain call to centuries of the unspectacular—to long, hard hours of painstaking thought and research. In fact, man has learned the value inherent in the unspectacular—in the "obvious"—and has built upon his investigations of the obvious all his scientific inquiry and knowledge. For example, man has taken an obvious fact—that he shares his planet with numerous other plant and animal species, each just as much alive as he—and, as it were, held this fact up to the light of reason and understanding, to derive additional information.

It is one of the cardinal principles of science that facts and ideas, however obvious and simple they appear, must be subjected to the closest of scrutiny. Thus, the scientist, like any questioning person, can obtain a glimpse of additional truths and insights from examining the simple fact that the human species is a co-inhabitant with myriads of other species. First, one can deduce rather easily that if many other things appear to be just as alive as man, then these things must contain

". . . so that the water ran in rivers, into great depressions that formed the oceans. In the ocean, living things originated . . ."

some vital factor—some life-giving substance or characteristics—in common with man. Second, one can assume that the study of other living things, given their degrees of commonality with the human species, can yield highly valuable information of matters concerning man himself.

Third, in view of the human penchant for creating order from chaos, the panorama and diversity of living things beckons the intellect of man, almost compels it, to somehow gain control, through understanding, of this huge manifestation of life. Indeed, having carefully observed the shades of similarity and difference among plant and animal life, man has succeeded in establishing for himself an extraordinarily developed system of classification in which most of the plant and animal species on this planet have been described. Man can now, as it were, breathe a sigh of relief with the assurance that there is, despite the tumultuous array, an underlying order and even unity among living organisms.

Finally, from the observation that life on this planet is almost incomprehensibly abundant, one may arrive at a heady respect for living things. Life is, in a sense, a battle for survival—a desperate struggle against the ever-present and inexorable tug of the forces of dissolution and lifelessness. It is the grandeur of life that, despite its delicate nature and the overwhelming obstacles endangering it, living things continue, through procreation and the consequent survival of their species. One of these living things—man—has even turned its intellect upon the study of the others. This study is called biology, the science of life.

The Characteristics of Life

It is not surprising that signs of life were the first concerns of moon-bound scientists. Indeed, biologists have traditionally been concerned with identifying the common characteristics of living things as a means for distinguishing them from non-living matter.

Living things always display four characteristics that are essentially unique to them. Briefly, the recognizable characteristics of living matter are the continual maintenance of some structure, the performance of metabolic functions, irritability or response to stimuli, and reproduction.

STRUCTURE

The structural diversity of organisms is enormous. Nevertheless, most living things are composed of basic structural units called cells. Some organisms are unicellular, their entire anatomy being limited to the confines of a single cell. Many organisms are multicellular; they are composed of many cells, some of which are highly specialized to perform specific functions and, in the higher organisms, are combined to form specific structures called tissues and organs. Thus, the complexity of an organism's overall structure may be readily understood in terms of the number and arrangement of its cells. Although most cells are replete with the subcellular organelles, it is the cell itself that is the basic functional unit common to most living things.

Interestingly enough, this generalization has led to some controversy. For although it seems tidy to assign a minimum degree of organization or structure found in the cell as a characteristic of living things, there is a category of things, the viruses, which lack most of the components found in even the most primitive cells, but which appear in many ways to be alive. Thus, it is probably safest to say that the cell shows the minimum degree of structure which constitutes an organism, but there are also viruses, and they may possibly be an exception to this generalization.

METABOLIC ACTIVITY

The maintenance of structure requires that an organism obtain substance and energy from its environment. This is accomplished through the processes of nutrition, the acquisition of nutrients from the environment, and metabolism, the breakdown of nutrients through respiration or fermentation. It is from the metabolism of nutrients that energy is released to be used by the organism to perform its many functions, all of which are designed to stave off the tendency toward dissolution and decay.

IRRITABILITY

All organisms must respond to alteration in their environment if they are to remain alive. In short, organisms must be able to maintain, within optimum ranges, their special internal environments, despite variations of external conditions. Thus, organisms must be capable of responding to changes of such environmental stimuli as light, temperature, and the concentration of chemicals in the environment. Unicellular organisms perform these vital responses within the confines of their single cells. In the most advanced multicellular organisms, this requirement is met by the function of special cells and organs, such as the cells that bend a leaf towards the light, or the organs, called kidneys, that prevent larger animals from drowning in their own fluids.

REPRODUCTION

No living thing continues to exist forever, nor does time affect all organisms equally. Some, like the bacterium, have a life span of hours; some, like the sequoia, live for thousands of years. Life's solution to individual death is the perpetuation of the individual's kind or species by the production of new organisms at some time prior to the death of those already existing.

Reproduction can occur at different levels, commensurate with the complexity of the organism. However, the process always depends upon some form of cellular division. Unicellular organisms grow to some size and divide to form two daughter cells; these can grow to form two adult unicellular organisms identical to the parent. Some multicellular organisms are dependent upon two parents and are said to reproduce sexually, but here, too, cell division is required to produce the special sex cells, or gametes, from which the new individual arises. As a new generation of organisms is thus reproduced, the particular species of which they are a part continues to survive.

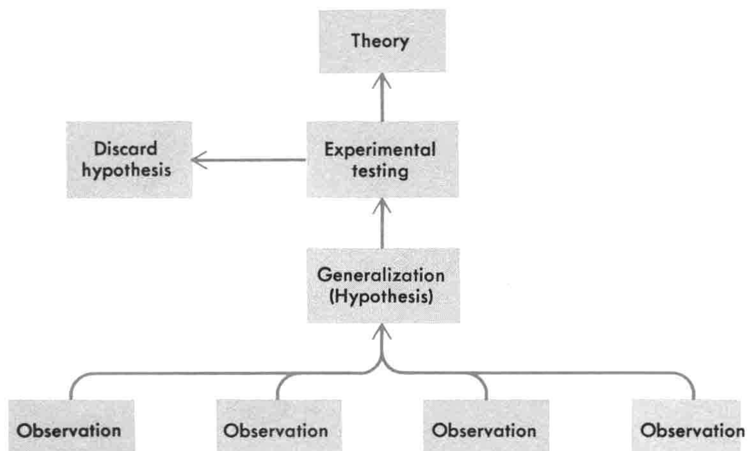
The Scientific Method

Any science, whether biology, physics, sociology, or chemistry, has as its primary aim the acquisition of knowledge. Yet the world around us is often not amenable to study because the subject matter it offers is fraught with factors that are highly variable. And these factors are so interrelated that alterations in any one of them are likely to affect the nature of the others. Moreover, the human mind is itself highly variable and capable of self-delusion and unconscious bias, thus distorting the facts that are perceived.

Although the aim of a science is the acquisition of information, the information must of course be reliable. Hence there is a necessity in the sciences for a systematized way of amassing knowledge. It is this systematization—known as the scientific method—that marks the essential difference between a science and any other discipline.

Before a scientist can effectively begin to study an area of interest to him, he first must acquaint himself with the research already done in the field and with the data obtained. This he may do by reading the journals that deal with his particular interest, or by attending meetings at which scientists present research papers, or even by avail-

FIGURE 1-1
The scientific method is shown in outline form.



ing himself of computerized research techniques. At the very least, this procedure lessens the possibility of duplication of effort, and is certainly likely to save the scientist much time.

After familiarizing himself with the intended field of study, the scientist is prepared to make his own observations of conditions and phenomena within the field. It is upon his observations, and the information he has obtained from the studies of others, that the scientist formulates a generalization, or a **hypothesis.** In his hypothesis he seeks to explain the facts in a way that permits him to test the validity of the explanation itself.

To test his hypothesis, an experimental framework is designed that permits the scientist to alter only one of the variables (or factors) in his hypothesis, and examine the effect of changes in the variable. For example, he may measure the effect of the variable temperature on the rate of reproduction of a bacterium. In order to be valid, the biologist's research must meet at least two criteria: it must be shown that only the one experimental variable is responsible for any observed changes, and, the results of his experimentation must be reproducible.

The scientist meets the first requirement by using what is known as a **control group.** The control group consists generally of a group or setup similar to the experimental group but one in which the experimental variable is never manipulated. For example, a biologist investigating the effect of heat on the reproductive rate of bacteria would vary the temperature in the experimental group, but maintain a constant temperature in the control group. If similar observations are made in both the experimental and control groups, the observed changes in both groups can be ascribed to random changes in the organisms. But if the experiment produces data which are significantly different

FIGURE 1-2

These rabbits are part of an experimental group used to detect possible irritating effects of medications intended for human use in and around the eyes. Medications are applied to the eyes of these rabbits, but not to those of a group otherwise identical to these experimental rabbits. If irritation develops with higher frequency in the experimental rabbits, researchers can attribute it to the use of the drugs, since that is the only difference between the two groups. Without the control group, other causes than the drugs could not be ruled out.