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OF

BIOLOGY

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To my wife, Lillian, for her patience

and to Sylvia, Ellen, and Judy

Preface

Biology has undergone tremendous changes since the seminal contributions of Watson and Crick inaugurated the era of molecular biology (1953). The more descriptive aspects of the field, long associated with the older notion of biology as natural history, have been complemented by investigative insights that afford an understanding of life in terms of the precise characteristics of macromolecules such as DNA, RNA, and protein. To a marked extent, heredity, development, the control of cell function and even evolution have become better understood by applying the probes of molecular biology.

However, the drama of life and its evolving diversity and scope, requires a perspective of time and an appreciation of meticulous descriptive detail to be truly appreciated. To cover these descriptive and historical aspects while elucidating with thoroughness the biochemical and molecular approaches imposes a daunting challenge to anyone undertaking a concise treatment of modern biology. Maintaining such a balance has been a continuing aim here.

In the outline format, each chapter independently summarizes the material of its major theme and is followed by a series of solved problems which provides both greater depth and an opportunity to clarify material which the student has not completely understood. All of the major themes expected in a one-year biology course at the introductory level are covered in the thirty-three chapters.

Although this book could serve as a primary text in elementary college biology, it is primarily intended as a supplementary text to improve the student's understanding and achievement in the course. In providing solutions to the problems in the latter part of each chapter, emphasis has been placed on clarity and the importance of mastering fundamentals. Many of the problems used here are derived from actual classroom situations.

Biology need not demand relevance. Our very aliveness underscores the intimacy of the connection between the discipline of biology and our everyday concerns. I trust that the material which has been gathered here will inspire understanding in its readers and promote an excitement and reverence for life as well as responsible conserving citizenship.

I should like to thank Elizabeth Zayatz, who played a significant role in encouraging me and filtering my original product through her keen editorial acumen. Thanks are due also to Meg Tobin, who guided the final steps of manuscript preparation. But my greatest debt is to the generations of students who shared in the adventure of the pursuit of knowledge.

GEORGE H. FRIED

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Chapter 1

The Basic Structure of Science

1.1 THE METHODS OF SCIENCE

Science is an organized system for the rigorous study of the natural world. It involves the application of the *scientific method* to problems formulated by trained minds in particular disciplines. Scientists may be interested in different aspects of nature, but they use a similar intellectual approach to guide their investigations.

Scientists must first formulate a problem to which they can then seek an answer. The answer generally involves an explanation relating to order or process in nature. The scientist is primarily interested in the mechanisms by which the natural world works rather than in questions of ultimate purpose.

Once a question has been raised, the scientist seeks answers by collecting data relevant to the problem. The data, which may consist of observations, measurements, counts, and a review of past records, are carefully sifted for regularity and relationships.

An educated guess, called a *hypothesis*, is then drawn up; this places the data into a conceptual framework. *Inductive logic* is used to formulate a hypothesis. This is a process of reasoning that usually begins with specific (or individual) pieces of data from which a general (or universal) premise is inferred.

EXAMPLE 1 A man takes up birdwatching and has occasion to observe mated pairs of many different kinds of birds. The man repeatedly sees only the drabber bird of any given pair lay eggs. From these observations, the man concludes that all male birds are colorful and all female birds are drab.

A hypothesis must be both logical and testable. Although the conclusion in Example 1 demonstrates the use of inductive logic, the conclusion cannot be tested and so, as stated, is useless as a scientific hypothesis. *Deductive logic*, in which the thought process is from the general to the specific, is used to state a hypothesis that can be tested. The "If . . . , then . . . " format is often used for this.

EXAMPLE 2 The conclusion in the previous example could be restated as: If birds of a particular *species* (i.e., birds capable of interbreeding to produce viable young) differ in color, then the more colorful ones are the males.*

After a workable hypothesis has been formulated, it is tested by constructing experiments and gathering new data, which in the end will either support or refute the hypothesis. *Note*: the application of the scientific method can be used to disprove a hypothesis, but *it can never prove anything absolutely*. Hence, a hypothesis that withstands the rigors of today's tests may have to be altered in the light of tomorrow's evidence.

An experiment must be so structured that the data gathered are free of bias and sampling error. Therefore, the validity of an experiment depends on a careful selection of organisms for the control and experimental groups, so that differences in age, genetic factors, previous treatment, etc., will not influence the results. Adequate numbers of individuals within each group are also crucial, since with small groups, individual peculiarities may be magnified. In addition, an experiment must be reproducible—i.e., other scientists must be able to repeat the experiment and get the same results.

EXAMPLE 3 A scientist wishes to know whether the addition of bone meal to the diet of cattle will improve their growth. On the basis of previous evidence of dietary benefits of bone meal to other animals, the scientist sets forth the hypothesis that the addition of bone meal to cattle feed will enhance growth in cattle. (*Note*: since all the cattle that have ever lived cannot be examined, this general statement can never be proved completely.)

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* Although this is often the case, the reverse is true for some species of sexually dimorphic birds.

To test the hypothesis, the scientist sets up two comparable groups of cattle. The *experimental group* is given bone meal in addition to other requisites for growth, while the second group, the *control group*, receives identical treatment *except* no bone meal is given. In a properly constructed experiment, any differences that develop between the control and experimental groups will be due to the single factor being tested. The two groups in this case differ only in presence or absence of bone meal in their diet, so any differences in growth patterns must be attributed to this substance. If the experimental group demonstrates improved growth relative to the control group, the results would support the hypothesis. Should the experimental group fail to undergo improvement in growth in comparison with the control group, then the hypothesis would be refuted. A poorer growth performance by the experimental group would not merely refute the hypothesis, but would suggest a possible inhibitory effect of bone meal on cattle growth; such a finding would lead to a new hypothesis.

As seen in Example 3, once the experiments have been completed, the results must be weighed to see if the hypothesis should be accepted, modified, or rejected.

It should be noted that scientists only rarely follow a prescribed program in a rigid manner. Hypotheses may precede the actual accumulation of data, or the data may be accumulated and analyzed and the hypothesis developed simultaneously rather than in an orderly progression. Also, although scientists are very inquisitive and highly creative in their thought processes, their curiosity may be constrained by previous, long-accepted views. Revolutionary departures from established concepts are relatively rare.

1.2 BIOLOGY AS A SCIENCE

Biologists apply the methods of science to arrive at an understanding of living organisms. Within the context of biology, it is useful to regard life as complex matter that is susceptible to analysis by chemical and physical approaches. Although there are many phenomena within living systems that appear to lie beyond this *mechanistic* approach, biologists have been most successful at reaching an understanding of life by focusing on those processes involving transformations of matter and energy. *A living organism* may thus be defined as a complex unit of physicochemical materials that is capable of self-regulation, metabolism, and reproduction. Furthermore, a living organism demonstrates the ability to interact with its environment, grow, move, and adapt.

Biologists cannot study all of life in their own lifetimes. Therefore, they divide the vastness of the living world into many different kinds of organisms and may confine their investigations to a particular type of organism or, alternatively, may study particular aspects of different kinds of organisms and their interactions with one another.

EXAMPLE 4 *Entomologists*, specialists in insect biology, devote their efforts to understanding the various facets of insects but do not become involved with other kinds of organisms. On the other hand, *developmental biologists* investigate the characteristics of embryo development in many different kinds of organisms but do not venture into investigating other areas.

The boundaries that mark these different areas of investigation provide biology with its specific disciplines, but these boundaries are in a constant state of flux.

1.3 THE SIGNIFICANCE OF EVOLUTION

In pursuing their investigation of the living world, biologists are guided by theories that bring order to life's diversity. In science, a *theory* is a hypothesis that has withstood repeated testing over a long period of time (in contrast to the lay meaning of unproved supposition or fanciful idea). The single significant theme that unifies all branches of biology is the concept of *evolution*, the theory that all living organisms have arisen from ancestral forms by continual modification through time. Evolution conveys the notion of change and development. The patterns of these changes reflect upon major investigative trends in all disciplines of biology.

The acceptance of evolution as an explanation of present-day biological diversity is comparatively recent. Many respected biologists of the nineteenth and early twentieth centuries firmly believed in the fixity of species. Even Charles Darwin only reluctantly came to accept evolution as an explanation for the diversity of life. A vestige of this long history of undynamic explanations for *speciation* (differentiation into new species) is the current *creationist* movement.

Although not widely accepted until recently, the concept of evolution is not new; however, an understanding of the *mechanism* of evolutionary change is only a little more than a century old. In 1801, Jean Baptiste Lamarck proposed the first comprehensive explanation for the mechanism of evolution. Lamarck believed that an adult organism acquired new characteristics in direct response to survival needs and then passed these new characteristics on to its offspring. We now know that inheritance is determined by genes, so that *acquired* characteristics cannot be passed on to offspring. Today, the mechanism of evolution is believed to be *natural selection*, a concept outlined by Charles Darwin in his book *On the Origin of Species by Means of Natural Selection*, published in 1859. In the book, Darwin presented a cogent series of arguments for evolution being the pervading theme of life.

Darwin was influenced not only by his experiences as a naturalist (biologist) during his 5-year voyage aboard a surveying vessel, the *Beagle*, but also by the findings of geologists, economists, and even farmers of his community. The universality of science is aptly illustrated in Darwin's conceptual development.

Natural selection favors the survival of those individuals whose characteristics render them best-adapted to their environment. Slight variations occur among offspring of all species, making them slightly different from their parents. If a variation is not favorable for survival, then the individuals having that trait either do not survive to reproduce or survive but produce fewer offspring. As a result, the unfavorable trait eventually disappears from the population. If, however, a variation enhances survival in that particular environment, the individuals possessing it are more likely to reproduce successfully and thereby pass the trait on to their offspring. In the course of time, the trait favoring survival becomes part of the general population.

EXAMPLE 5 Gibbons are small apes that spend most of their time in the uppermost parts of trees; they rarely descend to the ground and travel instead by *brachiating* (swinging from branch to branch). They feed on the foliage and fruits found in the tops of trees in their native southeastern Asia and East Indies. Gibbons' hands are long and spindly, with very short, thin thumbs. This anatomy enables gibbons to grasp branches easily and to dangle from branches, as well as to pluck fruits and buds. They cannot, however, easily pick up objects off a flat surface (e.g., the ground) or be otherwise dextrous with their hands (in contrast to gorillas and chimpanzees). The gibbons' environment does not require the latter characteristics for survival.

Descended from a common ancestor of all apes, the gibbons are possessed of a hand anatomy that evolved by the chance occurrence of traits that were then acted on by natural selection pressures of their environment—the tops of trees, a place where the species encounters little competition for food and faces few dangers from predators.

1.4 ORGANIZATION OF LIFE

The study of evolution is particularly useful for classifying organisms into groups because it reveals how organisms are chronologically and morphologically (by form and structure) related to each other. The classification of organisms is known as *taxonomy*. Taxonomists utilize evolutionary relationships in creating their groupings. Although classification schemes are, of necessity, somewhat arbitrary, they probably do reflect the "family tree" of today's diverse living forms.

All organisms belong to one of five major kingdoms. A *kingdom* is the broadest taxonomic category. The five kingdoms are Monera, Protista, Fungi, Plantae, and Animalia. The Monera consists of unicellular organisms that lack a nucleus and many of the specialized cell parts, called *organelles*. Such organisms are said to be *prokaryotic* (*pro* = "before"; *karyotic* = "kernal," "nucleus") and consist of bacteria. All of the other kingdoms consist of *eukaryotic* (*eu* = "true") organisms, which have cells that contain a nucleus and a fuller repertory of organelles. Unicellular eukaryotes are placed in kingdom

Protista, which includes the protozoans and plant and funguslike protists. Multicellular organisms that manufacture their own food are grouped into kingdom Plantae; flowers, mosses, and trees are examples. Uni- and multicellular plantlike organisms that absorb food from their environment are placed in kingdom Fungi, which includes the yeasts and molds. Multicellular organisms that must capture their food and digest it internally are grouped into kingdom Animalia; snakes and humans are examples.

Solved Problems

1.1 What is science?

Science is the systematic study of particular aspects of the natural world. The scope of science is limited to those things that can be apprehended by the senses (sight, touch, hearing, etc.). Generally, science stresses an *objective approach* to the phenomena that are studied. Questions about nature addressed by scientists tend to emphasize *how* things occur rather than *why* they occur.

1.2 What is the scientific method?

In the broadest sense, the scientific method refers to the working habits of practising scientists as their curiosity guides them in discerning regularities and relationships among the phenomena they are studying. A rigorous application of common sense to the study and analysis of data also describes the methods of science. In a more formal sense, the scientific method refers to the model for research developed by Francis Bacon (1561–1626). This model involves the following sequence:

1. Identifying the problem
2. Collecting data within the problem area (by observations, measurements, etc.)
3. Sifting the data for correlations, meaningful connections, and regularities
4. Formulating a hypothesis (a generalization), which is an educated guess that explains the existing data and suggests further avenues of investigation
5. Testing the hypothesis rigorously by gathering new data
6. Confirming, modifying, or rejecting the hypothesis in light of the new findings

1.3 What is the significance of the hypothesis in the scientific method?

The hypothesis makes up the lattice-work upon which scientific understanding is structured. Often called an "educated guess," the hypothesis constitutes a generalization that describes the state of affairs within an area of investigation. The formulation of fruitful hypotheses is the hallmark of the creative scientific imagination.

1.4 What is the inductive method in science?

In logic, *induction* usually refers to a movement from the particular to the general. Thus, the creation of a hypothesis (a generalization) from the particulars (specifics) of the data constitutes an inductive leap within the scientific method. Since the scientific method involves such an inductive process at its very core, it is often described as the *inductive method.*

It is of considerable historic interest that Bacon, who first developed what we now call the *scientific method,* was extremely suspicious of the inductive step for the development of hypotheses. He thought that with the garnering of sufficient data and the establishment of a large network of museums, the hidden truths of nature would be apparent without invoking induction.

1.5 Are hypotheses always designed to be true assumptions of an actual state of affairs?

Hypotheses are not designed to be true for all time. In fashioning a hypothesis, the scientist is aiming for *operational* truth, a "truth" that works as an explanation of the data but may be replaced as new data are found, rather like a mountain climber who clambers from one handhold to another in scaling a mountain. A hypothesis must be consistent with all data available and must provide a logical explanation of such data. However, many hypotheses do just that but appear to contradict a commonsense notion of truth. For example, light was found to exhibit the properties of a wave. Later, it was discovered to act also as a discrete particle. Which is correct? A hypothesis called *quantum theory* maintains that light is both a wave and a particle. Although this may offend our common sense and even challenge our capacity to construct a model of such a contradictory phenomenon, quantum theory is consistent with the data, explains it, and is readily accepted by physicists.

1.6 What are the characteristics of a good hypothesis?

1. A hypothesis must be consistent with and explain the data already obtained.
2. A hypothesis must be falsifiable through its predictions; that is, results must be obtainable that can clearly demonstrate whether the hypothesis is untrue.

If several competing hypotheses are contending for acceptance, the one that is simplest and clearest will probably be accepted within the scientific community. In its evaluation of hypotheses, science is also concerned with fruitfulness as well as with truthfulness.

1.7 What is the fate of hypotheses after they have been formulated?

A hypothesis undergoes rigorous testing and may be confirmed by experimental testing of its predictions. Repeated confirmations elevate the hypothesis to the status of a theory. Occasionally, the major tenets of a hypothesis are confirmed, but some modification of the hypothesis may occur in light of new evidence. When hypotheses have been repeatedly confirmed over long periods of time, they are sometimes designated as *laws*, although some philosophers of science disagree with the use of the term "scientific law." When hypotheses are substantially contradicted by new findings, they are rejected to make way for new hypotheses.

1.8 What factors might lead to the formulation of a hypothesis that does not stand up to further evidence?

Hypotheses are designed to explain what is currently known. New developments may lead to a broader view of reality that exposes inadequacies in a hypothesis formulated at an earlier time. More often, an investigator uncovers a group of facts not truly representative of the total and bases a hypotheses on this small or unrepresentative sample. Such *sampling error* can be minimized by using statistical techniques. Also, while science deservedly prides itself on its objectivity and basic absence of prejudgement, a *subjective bias* may intrude during the collection of data or in the framing of a hypotheses and thereby lead an investigator to ignore evidence that does not support a preconceived notion. Bias may also be involved in the tendency to assume the well-accepted ideas of established authorities.

1.9 Does adherence to the scientific method completely explain the development of modern science?

Present technology can be attributed in large part to trained professionals following the classical methods of science. However, such recent philosophers of science as Thomas Kühne have pointed out the role that subjective factors such as intuition and cultural influences have played in the world of science. In their view, attitudes and the potential for breakthroughs are influenced by a particular collective mindset, with science moving from one set of *paradigms* (intellectual models) to another in fits and starts. The generally accepted view that scientists are automatons proceeding from one phase of the scientific method to the next is simply not true. The personality and humanity of scientists will be coming under increasing scrutiny as society recognizes that financial backing, problems of ethics, and questions of survival are all part of the equation of modern science.

1.10 Can science be expected to solve all the world's mysteries and problems?

No. Science can successfully explain the forces that determine natural phenomena and has given us the power to control our environment to a considerable extent. However, science does not deal with the origin of the natural world but accepts its existence as a given. Nor can science answer questions of why the world exists as it does. Since hypotheses are judged in terms of their operational effectiveness, science cannot guide us in terms of morality, of the rightness or wrongness of particular courses of action. Science may best be viewed as an instrument for understanding rather than as a guide for social action.

1.11 What is a living organism?

A living organism is primarily physicochemical material that demonstrates a high degree of complexity, is capable of self-regulation, possesses a metabolism, and perpetuates itself through time. To many biologists, life is an arbitrary stage in the growing complexity of matter, with no sharp dividing line between the living and non-living worlds.

Living substance is composed of a highly structured array of macromolecules, such as proteins, lipids, nucleic acids, and polysaccharides, as well as smaller organic and inorganic molecules. A living organism has built-in regulatory mechanisms and interacts with the environment to sustain its structural and functional integrity. All reactions occurring *within* an individual living unit are called its *metabolism*. Specific molecules containing information in their structure are utilized both in the regulation of internal reactions and in the production of new living units.

1.12 What are the attributes of living organisms?

Living organisms generally demonstrate:

1. *Movement*: the motions within the organisms or movement of the organisms from one place to another (locomotion)
2. *Irritability*: the capacity of organisms to respond in a characteristic manner to changes—known as *stimuli*—in the internal and external environments
3. *Growth*: the ability of organisms to increase their mass of living material by assimilating new materials from the environment
4. *Adaptation*: the tendency of organisms to undergo or institute changes in their structure, function, or behavior that improve their capacity to survive in a particular environment
5. *Reproduction*: the ability of organisms to produce new individuals like themselves

1.13 How do biologists study living organisms?

The vast panorama of life is much too complicated to be studied in its entirety by any single investigator. The world of living things may be studied more readily by (1) dividing organisms into various kinds and studying one type intensively or (2) separating the investigative approaches and specializing in one or another of them.

Systems of classification of living organisms that permit the relative isolation of one or another type of organism for organized investigation have been constructed within biology. At one time all living organisms were subdivided into two fundamental groups, or *kingdoms*: the plants, the subject matter of *botany*, and the animals, the subject matter of *zoology*. At present, there are grounds for classifying all of life into five kingdoms. These kingdoms are further subdivided into smaller categories that give particular disciplines their subject material. Thus, biologists who study hairy, four-legged creatures that nurse their young (mammals) are called *mammologists*. Those who investigate soft-bodied, shelled animals are *malacologists*. The study of simple plants such as the mosses is carried out by *bryologists*.

Biological disciplines may also be differentiated according to *how* living organisms are studied. For example, *morphologists* concentrate on structure, while *physiologists* consider function. *Taxonomists* devote themselves to the science of classification, and *cytologists* study the cells, which are the basic units for all life. *Ecologists* deal with the interaction of organisms with each other and with their external environment. A relatively new but extremely exciting and fruitful branch of biology is *molecular biology*, which is the study of life in terms of the behavior of such macromolecules as proteins and nucleic acids. It is this branch of biology that has enabled us to understand life at the molecular level and even to change the hereditary characteristics of certain organisms in order to serve the needs of society.

1.14 Why does evolutionary theory occupy a central position in biology?

The variety and complexity of life require organizing principles to help understand so diverse a subject area. Evolution is a concept that provides coherence for understanding life in its totality. It presents a narrative that places living things in a historical perspective and explains the diversity of living organisms in the present. It also illuminates the nature of the interaction of organisms with each other and with the external environment. Classification today is almost entirely based on evolutionary relationships. Even the findings of molecular biology have been focused on the nature of evolutionary changes. Evolution is the key to understanding the dynamic nature of an unfolding world of living organisms.

1.15 What is evolution?

Evolution is a continuously substantiated theory that all living things have descended with modification from ancestral organisms in a long process of adaptive change. These changes have produced the organisms that have become extinct as well as the diverse forms of life that exist today. Although the pace of evolutionary changes in the structure, function, and behavior of groups of organisms is generally thought to be constant when viewed over very long periods of time, lively debate has ensued about the tempo of change when examined over shorter periods. The rate of change may not always be even but may occur in rapid bursts, and such abrupt changes have, in fact, been observed in some organisms.

1.16 Are there alternatives to the theory of evolution?

Although almost every practicing biologist strongly supports the theory of evolution, some nonbiologists believe that all living forms were individually created by a supernatural being and do not change in time. This view, known as *special creation*, is consistent with the biblical account of the origin and development of life. More recently, certain scientific facts have been incorporated into a more cohesive theory of *scientific creationism*, which attempts to meld the scientific with the biblical explanations by stating that life has indeed had a longer history than biblical accounts would support, but that living organisms show only limited changes from their initial creations. Although scientific creationists have sought to downplay the religious aspects of their theory and have demanded an opportunity to have their views represented in biology texts, most biologists do not accept these concepts as being valid scientifically. Thus far, the courts of the United States have interpreted scientific creationism to be an intrusion of religion into the secular realm of education.

1.17 What is the difference between evolution and natural selection?

Evolution is a scientifically accepted theory of the origin of present organisms from ancestors of the past, through a process of gradual modification. Natural selection is an explanation of how such changes might have occurred, i.e., the mechanism of evolution.

The concept of evolution existed among the Greeks of Athens. In the eighteenth century, the French naturalist Comte Georges de Buffon suggested that species may undergo change and that this may have contributed to the diversity of plant and animal forms. Erasmus Darwin, grandfather of Charles, also subscribed to the concept of changes in the lineage of most species, although his ideas do not seem to have played a role in the development of Charles Darwin's concept of evolutionary change.

The first comprehensive theory of a mechanism of evolution was advanced by Lamarck in 1801. Like Charles Darwin, Lamarck was profoundly influenced by new findings in geology, which suggested that the earth was extremely old and that present-day geological processes operated during past millennia.

1.18 What are the basic concepts of Lamarck's theory of the mechanism of evolution?

Lamarck believed that changes occur in an organism during its lifetime as a consequence of adapting to a particular environment. Those parts that are used tend to become prominent, while those that are not tend to degenerate (*use-disuse concept*). Further, the changes that occur in an organism during its lifetime are then passed onto its offspring; i.e., the offspring inherit these acquired characteristics. Integral to Lamarck's theory was the concept of a deep-seated impulse toward higher levels of complexity within the organism, as if each creature were endowed with the will to seek a higher station in life.

The chief defect in Lamarck's theory is the view that acquired characteristics are inherited. With our present understanding of the control of inheritance by the genetic apparatus, we realize that only changes in the makeup of genes could lead to permanent alterations in the offspring. However, at the time of Lamarck's formulation, little was known of the mechanism of genetics. Even Darwin incorporated some of the Lamarckian views of the inheritance of acquired characteristics into his own thinking.

Lamarck's theory of evolution should not be regarded as being merely a conceptual error. Rather, it should be viewed as a necessary step in a continuing development of greater exactness in the description of a natural process. Science moves in slow, tentative steps to arrive at greater certainty. The truths of today's science are dependent on the intellectual forays of earlier investigators. They provide the shoulders on which others may stand to reach for more fruitful explanations.

1.19 How does the theory of natural selection explain the process of evolution?

The Darwinian theory of the mechanism of evolution accounts for change in organisms as follows:

1. In each generation many more young are produced than can possibly survive, given the limited resources of a habitat, the presence of predators, the physical dangers of the environment, etc.
2. As a result, a competition for survival ensues within each species.
3. The original entrants in the competition are not exactly alike but, rather, tend to vary to a greater or lesser degree.
4. In this contest, those organisms that are better adapted to the environment tend to survive. Those that are less fit tend to die out. The natural environment is the delineating force in this process.
5. The variants that survive and reproduce will pass their traits on to the next generation.
6. Over the course of many generations, the species will tend to reflect the characteristics of those who have been most successful at surviving, while the traits of those less well adapted will tend to die out.

Darwin was not certain about the source of variation in offspring, but he was aware of the existence of heritable variations within a species. We would now attribute these variations to the shuffling of genes associated with sexual reproduction (Chap. 8) and to the changes, known as *mutations*, in the structure of genes.

1.20 What does "survival of the fittest" mean?

The selection process arises from the fact that the best-adapted organisms tend to survive, almost as if nature had handpicked a fortunate few for perpetuation. At its heart, fitness has little to do with which individuals survive the longest or are the strongest; rather, it is determined by which ones pass on their genes to the next generation. It is true, though, that the longest-lived individual may have more time to produce offspring and the strongest may have more opportunity to mate. In both cases, therefore, *reproductive* success is the key. Present organisms can trace their lineage through a long series of past reproductive winners in the battle for survival.

It should be realized that reproductive success is not just a matter of active combat for resources and mates, but may involve cooperative and altruistic features by which individual success may be enhanced. Nor is the competition an all-or-none affair in which there is a single winner and many losers. Rather, one might view the struggle for existence and the survival of the fittest as a mechanism for *differential* reproduction—those with better adaptations outproduce those of lesser "fitness." Over long periods of time, the species tends to hoard those genes that are passed on by the better-adapted individuals.

1.21 If evolution results in increasing fitness within each species, will we eventually reach a point of perfect fitness and end the possibility of further change?

No. This will not occur, because the environment is constantly changing and today's adapted group becomes tomorrow's anachronism. Thus, the process is never-ending. More than 95 percent of all the species that have evolved in time have become extinct, probably because of the changing features of the