THIS IS BIOLOGY

The Science of the Living World

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CHAPTER TWO

What Is Science?

Biology encompasses all of the disciplines devoted to the study of living organisms. Sometimes these disciplines are referred to as the life sciences—a useful term that distinguishes biology from the physical sciences, whose focus is on the inanimate world. The social sciences, political science, military science, and many others comprise yet other systematized bodies of knowledge, and in addition to these academic specialties, we frequently encounter Marxist science, Western science, feminist science, and such putative sciences as Christian science and creationist science. Why do all of these various disciplines call themselves "science"? What are the characteristics of a true science that distinguish it from other systems of thought? Does biology have these features?

It should be easy to answer these basic questions, one would think. Doesn't everybody know what science is? That this is not the case is evident when one studies not just the offerings of the popular press but also the enormous professional literature dealing with this question.[1] T. H. Huxley, a friend of Charles Darwin and a popularizer of Darwin's theories, defined science as "nothing but trained and organized common sense." Alas, this is not true. Common sense is frequently corrected by science. For instance, common sense tells us that the earth is flat and that the sun circles the earth. In every branch of science there have been commonsense opinions that have subsequently been proven wrong. One might go so far as to say that scientific activity consists of either confirming or refuting common sense.

A number of factors account for the difficulties philosophers have encountered in agreeing upon a definition of science. One of them is that science is both an activity (that which scientists do) and a body of knowledge (that which scientists know). Most philosophers today, in their definition of science, emphasize the ongoing activity of scientists: exploration, explanation, and testing. But other philosophers tend to define science as a growing body of knowledge, "the organization and classification of knowledge on the basis of explanatory principles."[2]

Emphasis on the collection of data and the accumulation of knowledge is a residue of the early days of the Scientific Revolution, when induction was the preferred method of science. There was a widespread misconception among inductionists that a pile of facts would not only permit generalizations but almost automatically produce new theories, as if by spontaneous combustion. Actually, philosophers today generally agree that facts alone do not explain, and they even argue a great deal over the question whether pure facts exist at all. "Are not all observations theory-laden?" they have asked. Even this is not a new concern. As far back as 1861, Charles Darwin wrote, "How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service."

To be sure, most authors who use the word "knowledge" mean it to include not just facts but also an interpretation of the facts; it is less confusing, however, to use the word "understanding" for this meaning. Hence the definition, "The aim of science is to advance our understanding of nature." Some philosophers would add "by solving scientific problems."[3] Some have gone further and have said, "The aims of science are to understand, predict, and control." Yet there are many branches of science in which prediction plays a very subordinate role, and in many of the nonapplied sciences the question of control never comes up.

Another reason for the difficulties philosophers have had in agreeing on a definition of science is that the endeavors which we call science have changed continually over the centuries. For example, natural theology—the study of nature for the purpose of understanding God's intentions—was considered a legitimate branch of science until about 150 years ago. As a result, in 1859 some of Darwin's critics chided him for including in his account of the origin of species such an "unscientific" factor as chance, while ignoring what they clearly saw as the hand of God in the design of all creatures great and small. Yet in the twentieth century we have witnessed a complete reversal in scientists' view of random phenomena: in both the life sciences and the physical sciences there has been a change from a strictly deterministic notion of how the natural world works to a conception that is largely probabilistic.

To take another example of how science is gradually changing, the strong empiricism of the Scientific Revolution led to a heavy emphasis on the discovery of new facts, while curiously little reference was made to the important role that the development of new concepts plays in the advancement of science. Today, concepts such as competition, common descent, territory, and altruism are as significant in biology as laws and discoveries are in the physical sciences, and yet their importance was strangely ignored until quite recently. This neglect is reflected, for example, in the provisions established for Nobel Prizes. Even if there were a Nobel Prize in biology (which there is not), Darwin could not have been awarded a prize for the development of the concept of natural selection—surely the greatest scientific achievement of the nineteenth century—because it was not a discovery. This attitude which favors discoveries over concepts continues into the present day, but to a lesser extent than in Darwin's time.

No one knows what other changes in our image of science the future may bring. The best one can do under the circumstances is to try to present an outline of the kind of science that prevails in our time, at the end of the twentieth century.

The Origins of Modern Science

Modern science began with the Scientific Revolution, that remarkable achievement of the human intellect characterized by the names Copernicus, Galileo, Kepler, Newton, Descartes, and Leibniz. At that time many of the basic principles of the scientific method were developed which still largely characterize science today. What one considers science is, of course, a matter of opinion. In some respects Aristotle's biology was also science, but it lacked the methodological rigor and comprehensiveness of the science of biology as it developed from 1830 to the 1860s.

The scientific disciplines that gave rise to the prevailing concept of science during the Scientific Revolution were mathematics, mechanics, and astronomy. How large a contribution scholastic logic made to the original framework of this physicalist science has not yet been fully determined; it certainly played a major role in Descartes's thinking. The ideals of this new, rational science were objectivity, empiricism, inductivism, and an endeavor to eliminate all remnants of metaphysics—that is, magical or superstitious explanations of phenomena that were not grounded in the physical world.

Virtually all architects of the Scientific Revolution remained devout Christians, however; and, not surprisingly, the kind of science they created was very much a branch of the Christian faith. In this view, the world was created by God and thus it could not be chaotic. It was governed by His laws, which, because they were God's laws, were universal. An explanation of a phenomenon or process was considered to be sound if it was consistent with one of these laws. With the workings of the cosmos thus ultimately clear-cut and absolute, it should be possible eventually to prove and predict everything. The task of God's science, then, was to find these universal laws, to find the ultimate truth of everything as embodied in these laws, and to test their truth by way of predictions and experiments.

As far as mechanics was concerned, matters conformed rather well to this ideal. Planets orbited the sun and balls rolled down inclined planes in a predictable manner. Perhaps it was not an accident of history that mechanics, being the simplest of all sciences, was the first to develop a set of coherent laws and methods. But as the other branches of physics developed, exceptions to the universality and determinacy of mechanics were found again and again, requiring various modifications. Indeed, in everyday life the laws of mechanics are often so completely thwarted by random (stochastic) processes that determinacy appears to be totally absent. For instance, so much turbulence usually accompanies the movement of air masses and water masses that the laws of mechanics do not permit long-term predictions in either meteorology or oceanography.

The mechanists' recipe for the natural world worked even less well for the biological sciences. There was no room in the scientific method of the mechanists for the reconstruction of historical sequences, as occurred in the evolution of life, nor for the pluralism of answers and causations that make prediction of the future in the biological sciences impossible. When evolutionary biology was examined for its "scientificness" according to the criteria of mechanics, it flunked the test.

This was particularly true when it came to the favorite investigative method of mechanics: the experiment. The experiment was so valuable in this field that eventually it came to be treated as if it were the *only* valid scientific method. Any other method was considered inferior science. But since it was not in good taste to call one's colleagues bad scientists, these other nonexperimental sciences came to be called descriptive sciences. This term was for centuries pejoratively attached to the life sciences.

Actually, our basic knowledge in *all* sciences is based upon description. The younger a science is, the more descriptive it has to be to lay a factual foundation. Even today, most publications in molecular biology are essentially descriptive. What is really meant by "descriptive" is "observational," for all description is based on observation, whether by the naked eye or other sense organs, by simple microscopes or telescopes, or by means of highly sophisticated instrumentation. Even during the Scientific Revolution, observation (rather than experimentation) played a decisive role in the advance of science. The cosmological generalizations of Copernicus, Kepler, and for the most part Newton were based on observation rather than on laboratory experiments. Today, the underlying theories in fields such as astronomy, astrophysics, cosmology, planetary science, and geology change frequently as a result of new observations that have little if anything to do with experimentation.

One might put it another way and say that the findings described by Galileo and his followers came from the experiments of nature they were able to observe. The eclipses and occlusions of planets and stars are natural experiments, as are earthquakes, volcanic eruptions, meteor craters, magnetic shifts, and erosion events. In evolutionary biology, the joining of North and South America in the Pliocene through the Isthmus of Panama, which resulted in a massive faunal interchange of the two continents, is one such experiment; the colonization of volcanic islands and archipelagos such as Krakatau, the Galapagos, and the Hawaiian Islands, not to mention the defaunation and subsequent recolonization of much of the northern hemisphere owing to the Pleistocene glaciations, are other natural experiments. Much progress in the observational sciences is due to the genius of those who have discovered, critically evaluated, and compared such natural experiments in fields where a laboratory experiment is highly impractical, if not impossible.

A revolution in thought though the Scientific Revolution was—by abandoning superstition, magic, and the dogmas of medieval theologians—it nevertheless did not include a revolt against allegiance to the Christian religion, and this ideological bias had adverse consequences for biology. The answer to the most basic problems in the study of living organisms depends on whether or not one invokes the hand of God. This is particularly true for all questions of origin (the subject matter of interest to creationists) and design (the subject matter of interest to natural theologians). The acceptance of a universe containing nothing but God, human souls, matter, and motion worked fine for the physical sciences of the day, but it worked against the advance of biology.[4]

As a result, biology was basically dormant until the nineteenth and twentieth centuries. Although a considerable amount of factual knowledge in natural history, anatomy, and physiology was accumulated during the seventeenth and eighteenth centuries, the world of life at that time was considered to belong to the realm of medicine; this was true for anatomy and physiology, indeed, even for botany, which largely consisted of the identification of medicinally important plants. To be sure, there was also some natural history, but either it was practiced as a hobby or it was pursued in the service of natural theology. In retrospect, it is evident that some of this early natural history was very good science; but, not being recognized as such at that time, it did not contribute to the philosophy of science.

Finally, the acceptance of mechanics as the exemplar of science led to the belief that organisms are in no way different from inert matter. From this followed logically the conclusion that the goal of science was to reduce all of biology to the laws of chemistry and physics. In due time developments in biology made this position untenable (see Chapter 1). The eventual overthrow of mechanicism and its nemesis, vitalism, and the acceptance in the twentieth century of the paradigm of organicism have had a profound impact on the position of biology among the sciences—an impact not yet fully appreciated by many philosophers of science.

Is Biology an Autonomous Science?

After the middle of the twentieth century, one could discern three very different views on the position of biology in the sciences. According to one extreme, biology is to be excluded from science altogether because it lacks the universality, the law-structuredness, and strictly quantitative nature of a "true science" (meaning physics). According to the other extreme, biology not only has all the necessary attributes of a genuine science but differs from physics in important respects so that it is to be ranked as an autonomous science, equivalent to physics. Between these two extremes is the view that biology should be accorded the status of a "provincial" science, because it lacks universality and because its findings can ultimately be reduced to the laws of physics and chemistry.

The question "Is biology an autonomous science?" can be rephrased in two parts: "Is biology, like physics and chemistry, a science?" and "Is biology a science exactly like physics and chemistry?" To answer the first question, we might consult John Moore's eight criteria for determining whether a certain activity qualifies as science. According to Moore (1993): (1) A science must be based on data collected in the field or laboratory by observation or experiment, without invoking supernatural factors. (2) Data must be collected to answer questions, and observations must be made to strengthen or refute conjectures. (3) Objective methods must be employed in order to minimize any possible bias. (4) Hypotheses must be consistent with the observations and compatible with the general conceptual framework. (5) All hypotheses must be tested, and, if possible, competing hypotheses must be developed, and their degree of validity (problem-solving capacity) must be compared. (6) Generalizations must be universally valid within the domain of the particular science. Unique events must be explicable without invoking supernatural factors. (7) In order to eliminate the possibility of error, a fact or discovery must be fully accepted only if (repeatedly) confirmed by other investigators. (8) Science is characterized by the steady improvement of scientific theories, by the replacement of faulty or incomplete theories, and by the solution of previously puzzling problems.

Judging by these criteria, most people would conclude that biology should be considered, like physics and chemistry, a legitimate science. But is biology a provincial science, and therefore not on a par with the physical sciences? When the term "provincial science" was first introduced, it was used as an antonym to "universal," meaning that biology dealt with specific and localized objects about which one could not propose universal laws. The laws of physics, it was said, have no limitations of time or space; they are as valid in the Andromeda galaxy as on earth. Biology, by contrast, is provincial because all life that we know of has existed only on the earth, and only for 3.8 billion of the 10 billion or more years since the Big Bang.

This argument was convincingly refuted by Ronald Munson (1975), who showed that none of the fundamental laws, theories, or principles of biology are either implicitly or explicitly restricted in their scope or range of application to a certain region of space or time. There is a great deal of uniqueness in the world of life, but one can make all sorts of generalizations about unique phenomena. Each ocean current is also unique, but we can establish laws and theories about ocean currents. As for the argument that the restriction of known life to the earth deprives biological principles of all universality, here we must ask, "What is 'universal'?" Since inanimate matter is known to exist outside the earth, any science dealing with inanimate matter must be applicable extraterrestrially in order to be universal. Life, so far, has been demonstrated for the earth only; yet its laws and principles (like those of inanimate matter) are universal because they are valid on the earth, the known domain of its existence. I can see no reason for withholding the designation "universal" from a principle that is true for the entire domain for which it is applicable.

More often, when biology is described as a "provincial" science, what is meant is that it is a subset of physics and chemistry, and that ultimately the findings of biology can be reduced to chemical and physical theories. By contrast, an advocate of the autonomy of biology might argue in the following way: Many attributes of living organisms that interest biologists cannot be reduced to physicochemical laws, and, moreover, many aspects of the physical world studied by physicists are not relevant to the study of life (or to any other science outside of physics). In this sense physics is as provincial a science as biology. There is no reason to consider physics as an exemplar merely because it was the first well-organized science. That historical fact does not make it any more universal than its younger sibling, biology. A unity of science cannot be achieved until it is accepted that science contains a number of separate provinces, one of which is physics, another of which is biology. It would be futile to try to "reduce" biology, one provincial science, to physics, another provincial science, or vice versa.[5]

Many, if not most, of the promoters of the unity of science movement in the late nineteenth and early twentieth centuries were philosophers rather than scientists and had little awareness of the heterogeneity of the sciences. This applies to the physical sciences—which include elementary particle physics, solid state physics, quantum mechanics, classical mechanics, relativity theory, electromagnetism, not to mention geophysics, astrophysics, oceanography, geology, and others—and increases exponentially when we think of the many life sciences. The impossibility of reducing all these domains to a single common denominator has been demonstrated again and again during the past 70 years.

So to reiterate: Yes, biology is, like physics and chemistry, a science. But biology is not a science like physics and chemistry; it is rather an autonomous science on a par with the equally autonomous physical sciences. Nevertheless, one would not be able to speak of science in the singular if not all sciences, in spite of their unique features and a certain amount of autonomy, did not share common features. One of the tasks of the philosopher of biology is to establish what the common features are which biology shares with the other sciences, not only in methodology but also in principles and concepts. And these common features would define a unified science.

The Concerns of Science

It has been said that the scientist searches for truth, but many people who are not scientists claim the same. The world and all that is in it are the sphere of interest not only of scientists but also of theologians, philosophers, poets, and politicians. How can one make a demarcation between their concerns and those of the scientist?

HOW SCIENCE DIFFERS FROM THEOLOGY

The demarcation between science and theology is perhaps easiest, because scientists do not invoke the supernatural to explain how the natural world works, and they do not rely on divine revelation to understand it. When early humans tried to give explanations for natural phenomena, particularly for disasters, invariably they invoked supernatural beings and forces, and even today divine revelation is as legitimate a source of truth for many pious Christians as is science. Virtually all scientists known to me personally have religion in the best sense of this word, but scientists do not invoke supernatural causations or divine revelation.

Another feature of science that distinguishes it from theology is its openness. Religions are characterized by their relative inviolability; in revealed religions, a difference in the interpretation of even a single word in the revealed founding document may lead to the origin of a new religion. This contrasts dramatically with the situation in any active field of science, where one finds different versions of almost any theory. New conjectures are made continuously, earlier ones are refuted, and at all times considerable intellectual diversity exists. Indeed, it is by a Darwinian process of variation and selection in the formation and testing of hypotheses that science advances (see Chapter 5).

Despite the openness of science to new facts and hypotheses, it must be said that virtually all scientists—somewhat like theologians—bring a set of what we might call "first principles" with them to the study of the natural world. One of these axiomatic assumptions is that there *is* a real world, independent of human perceptions. This might be called the principle of objectivity (as opposed to subjectivity) or commonsense realism (see Chapter 3). This principle does not mean that individual scientists are always "objective" or even that objectivity among human beings is possible in any absolute sense. What it does mean is that an objective world exists outside of the influence of subjective human perception. Most scientists—though not all—believe in this axiom.

Second, scientists assume that this world is not chaotic but is structured in some way, and that most, if not all, aspects of this structure will yield to the tools of scientific investigation. A primary tool used in all scientific activity is testing. Every new fact and every new explanation must be tested again and again, preferably by different investigators using different methods (see Chapters 3 and 4). Every confirmation strengthens the probability of the "truth" of a fact or explanation, and every falsification or refutation strengthens the probability that an opposing theory is correct. One of the most characteristic features of science is this openness to challenge. The willingness to abandon a currently accepted belief when a new, better one is proposed is an important demarcation between science and religious dogma.

The method used to test for "truth" in science will vary depending on whether one is testing a fact or an explanation. The existence of a continent of Atlantis between Europe and America became doubtful when no such continent was discovered during the first few Atlantic crossings in the period of discoveries during the late fifteenth and early sixteenth centuries. After complete oceanographic surveys of the Atlantic Ocean were made and, even more convincingly, after photographs from satellites were taken in this century, the new evidence conclusively proved that no such continent exists. Often, in science, the absolute truth of a fact can be established. The absolute truth of an explanation or theory is much harder, and usually takes much longer, to gain acceptance. The "theory" of evolution through natural selection was not fully accepted as valid by scientists for over 100 years; and even today, in some religious sects, there are people who do not believe it.

Third, most scientists assume that there is historical and causal continuity among all phenomena in the material universe, and they include within the domain of legitimate scientific study everything known to exist or to happen in this universe. But they do not go beyond the material world. Theologians may also be interested in the physical world, but in addition they usually believe in a metaphysical or supernatural realm inhabited by souls, spirits, angels, or gods, and this heaven or nirvana is often believed to be the future resting place of all believers after death. Such supernatural constructions are beyond the scope of science.

HOW SCIENCE DIFFERS FROM PHILOSOPHY

The demarcation between science and philosophy is more difficult to determine than that between science and theology, and this led to tension between scientists and philosophers throughout most of the nineteenth century. Philosophy and science were a single endeavor at the time of the Greeks. The beginning of a separation of the two took place in the Scientific Revolution; but right up to Immanuel Kant, William Whewell, and William Herschel, many people who contributed to the advance of science were also philosophers. Later authors, like Ernst Mach or Hans Driesch, started out as scientists and then switched to philosophy.

Is there, perhaps, no demarcation at all between science and philosophy? The search for and discovery of facts is surely the business of science; but elsewhere there is a considerable area of overlap. Theorizing, generalizing, and establishing a conceptual framework for their field is considered by most scientists to be part of their job; indeed, it is this that makes the real scientist. Yet many philosophers of science have felt that theorizing and concept formation are the domain of philosophy. For better or for worse, in recent decades most of this endeavor has now been taken over by scientists, and some basic concepts developed by biologists have subsequently been taken up by philosophers and are now also concepts of philosophy.

To replace their former chief concern, philosophers of science have specialized in elucidating the principles whereby theories or concepts are formed. They search for the rules that specify the operations by which scientists answer the "What?" "How?" and "Why?" questions they encounter. The major domain of philosophy relating to science is now the testing of "the logic of justification" and the methodology of explanation (see Chapter 3). At its worst, this type of philosophy tends to degenerate into logic-chopping and semantic quibbling. At its best, it has forced scientists into responsibility and precision.

Although philosophers of science often state that their methodological rules are merely descriptive and not prescriptive, many of them seem to consider it their task to determine what scientists *should* be doing. Scientists usually pay no attention to this normative advice but rather choose that approach which (they hope) will lead most quickly to results; these approaches may differ from case to case.

Perhaps the greatest failing of the philosophy of science, until only a few years ago, was that it took physics as the exemplar of science. As a result, the so-called philosophy of science was nothing but a philosophy of the physical sciences. This has changed under the influence of the younger philosophers, many of whom specialize in the philosophy of biology. The intimate connection that exists today between philosophy and the life sciences is evident from the many articles published in the journal *Biology and Philosophy.* Through the efforts of these young philosophers, the concepts and methods used in the biological sciences have now become important components of the philosophy of science.

This is a most desirable development for both philosophy and biology. It should be the aim of every scientist to eventually generalize his views of nature so that they make a contribution to the philosophy of science. As long as the philosophy of science was restricted to the laws and methods of physics, it was not possible for biologists to make such a contribution. Fortunately, this is no longer the case.

The incorporation of biology has modified many of the tenets of the philosophy of science. As we will see in Chapters 3 and 4, the rejection of strict determinism and of reliance on universal laws, the acceptance of merely probabilistic prediction and of historical narratives, the acknowledgment of the important role of concepts in theory formation, the recognition of the population concept and of the role of unique individuals, and many other aspects of biological thought have affected the philosophy of science fundamentally. With probabilism now dominant, all aspects of logical analysis that are based on typological assumptions have become highly vulnerable. The complete certainty which, following Descartes, had been the ideal of the philosophers of science seems less and less important as a goal.

HOW SCIENCE DIFFERS FROM THE HUMANITIES

As far as the demarcation between science and the humanities is concerned, the tendency of writers in the past to ignore the heterogeneity of both fields has led to many misconceptions. There is more difference between physics and evolutionary biology—both of which are branches of science—than between evolutionary biology (one of the sciences) and history (one of the humanities). Literary criticism has virtually nothing in common with most of the other disciplines of the humanities and even less with science.

When C. P. Snow wrote his *Two Cultures* in 1959, what he actually described was the gap between physics and the humanities. Like others of that era, he naively assumed that physics could stand for science as a whole. The gap between physics and the humanities, as he rightly pointed out, is indeed virtually unbridgeable. There is simply no pathway from physics to ethics, culture, mind, free will, and other humanistic concerns. The absence in physics of these important topics contributed to the alienation of scientists and humanists that Snow decried. Yet, all these concerns have substantial relationships with the life sciences.

Similarly, when E. M. Carr (1961), a humanist, contrasted history with "the sciences," he found five respects in which they differ: (1) History, he said, deals exclusively with the unique, science with the general. (2) History teaches no lessons. (3) History, unlike science, is unable to predict. (4) History is necessarily subjective, while science is objective. (5) And history, unlike science, touches upon issues of religion and morality. What Carr failed to see was that these differences are valid only for the physical sciences and for much of functional biology. However, statements 1, 3, and 5 apply as well to evolutionary biology as to history, and, as Carr admits, some of these claims (statement 2, for instance) are not strictly true even for history. In other words, the sharp break between the "sciences" and the "nonsciences" does not exist, once biology is admitted into the realm of science.[6]

Quite often the estrangement between science and the humanities is assigned to the failure of scientists to appreciate the "human element" as they go about their research. Yet not all of the blame should be shouldered by scientists. A rudimentary knowledge of certain findings of science, particularly of evolutionary biology, behavioral science, human development, and physical anthropology, is indispensable for most work in the humanities. Yet, all too many humanists have failed to acquire such a knowledge and display an embarrassing ignorance of these subjects in their writings. Many excuse their poor understanding of science with the statement, "I have no ability in mathematics." Actually, there is little mathematics in those parts of biology with which the humanists should most familiarize themselves. For instance, there is not a single mathematical formula in Darwin's *Origin of Species* or in my *Growth of Biological Thought* (1982). An understanding of human biology should be a necessary and inseparable component of studies in the humanities. Psychology, formerly classified with the humanities, is now considered a biological science. Yet, how can one write anything in the humanities, whether in history or literature, without having a considerable understanding of human behavior?

Snow correctly emphasized this point. There is a deplorable ignorance among most people of even the simplest facts of science. For example, writer after writer still states that he cannot believe that the eye is the result of a series of accidents. What this statement reveals is that the writer has no understanding of the workings of natural selection, which is an *anti*chance—rather than an accidental—process. Evolutionary change occurs because certain characteristics of individuals are better suited to the current environmental circumstances of a species than are others, and these more adaptive features become concentrated in later generations through differential rates of survival and reproduction—in other words, through selection. Chance certainly plays a part in evolution, as Darwin knew very well, but natural selection—the primary mechanism of evolutionary change—is not an accidental process.

An ignorance of the findings of biology is particularly damaging whenever humanists are forced to confront such political problems as global overpopulation, the spread of infectious diseases, the depletion of nonrenewable resources, deleterious climatic changes, increased agricultural requirements worldwide, the destruction of natural habitats, the proliferation of criminal behavior, or the failures of our educational system. None of these problems can be satisfactorily addressed without taking into account the findings of science, particularly biology, and yet too often politicians proceed in ignorance.

The Objectives of Scientific Research

It is often asked why do we do science? Or, what is science good for? Two rather different answers to this question have been given. The insatiable curiosity of human beings, and the desire for a better understanding of the world they live in, is the primary reason for an interest in science by most scientists. It is based on the conviction that none of the philosophical or purely ideological theories of the world can compete in the long run with the understanding of the world produced by science.

To make a contribution to this better understanding of the world is a source of great satisfaction to a scientist; indeed it is an occasion for exhilaration. The emphasis is often on discovery, where luck sometimes plays a role, but the joy is perhaps even greater when one succeeds in the difficult intellectual achievement of developing a new concept, a concept that can integrate a mass of previously disparate facts, or one that is more successful as the basis of scientific theories. Offsetting the joy of research, of course, is the incessant need for dull data-collecting, the disappointment (if not embarrassment) of invalid theories, the recalcitrance of certain research subjects, and a multitude of other frustrations.[7]

An entirely different objective is to use science as a means to control the world, its forces and resources. This second objective is held particularly by applied scientists (including those in medicine, public health, and agriculture), engineers, politicians, and the average citizen. But what some politicians and voters forget is that when it comes to the ills of pollution, urbanization, famine, or the population explosion, it is not sufficient to fight the symptoms. One does not cure malaria with aspirin, and one cannot fight social and economic ills without going into the causes. Our way of dealing with racial discrimination, crime, drug addiction, homelessness, and similar problems, and the success we will have in eliminating them, will depend to a considerable extent on our understanding of their biological roots.

These two objectives of science—satisfying curiosity and making improvements in the world—are not entirely different domains, because even applied science, particularly all science on which public policy is based, relies on basic science. In most cases scientists are largely motivated by the simple desire for a better understanding of puzzling phenomena in our world.

In both basic and applied science, any discussion of the objectives of scientific research always entails questions of values. To what extent can our society afford certain big science projects, like the superconducting supercollider or the space station, considering the narrowness of the results we can expect to obtain? To what extent should one consider certain experiments, particularly with mammals (dogs, monkeys, apes) as unethical? Is there a danger that work with human embryonic materials might lead to unethical practices? What experiments in human psychology or clinical medicine might be harmful to the experimental subjects?

As long as the physical sciences were dominant, science was usually considered to be value-free. During the student rebellion of the 1960s, some groups who resented this arrogance promoted the slogan "Down with value-free science." Since the rise of biology, and particularly of genetics and evolutionary biology, it has become clear that scientific findings and theories have an impact on values, though to what extent science can generate values is unclear (see Chapter 12). Some of Darwin's opponents, such as Adam Sedgwick, accused Darwinism of destroying moral values. Even today, creationists fight evolutionary biology because they are convinced that it undermines the values of Christian theology. The eugenics movement in this century clearly derived its values from the science of human genetics. And the reason why sociobiology was attacked so viciously in the 1970s was that it seemed to promote certain political values incompatible with those of its opponents. Almost all major religious and political ideologies uphold values that are claimed to derive from science, and almost all ideologies uphold other values that are incompatible with certain findings of science.

Paul Feyerabend (1970) has ventured to suggest (as have other contemporary writers) that a world without science "would be more pleasant than the world we live in today." I am not sure that this is true. There would be less pollution and pollution-caused cancer, less crowding, and fewer of the adverse by-products of mass society. But it would also be a world with high infant mortality, a life span of only 35–40 years, no way of escaping summer heat and protecting oneself against severe winter cold. It is all too easy to forget the vast benefits of science (including agricultural and medical science) when one is complaining about its deleterious side effects. Most of these so-called evils of science and technology could be eliminated; scientists know what should be done, but their knowledge must be translated into legislation and its enforcement, and this has so far been resisted by the politicians and much of the voting public.

My own view of the contributions of science is more in line with that of Karl Popper, who had this to say: "Next to music and art, science is the greatest, most beautiful and most enlightening achievement of the human spirit. I abhor the at present so noisy intellectual fashion that tries to denigrate science, and I admire beyond anything the marvelous results achieved in our time by the work of biologists and biochemists and made available through medicine to sufferers all over our beautiful earth."

SCIENCE AND THE SCIENTIST

One frequently hears that science can do this, or science cannot do that, but of course it is scientists who either can or cannot do something. A scientist at his or her best is dedicated, highly motivated, scrupulously honest, generous, and cooperative. Scientists are only human, however, and do not always live up to these professional ideals. Political, theological, or financial considerations that arise from outside of science should not, but often do, affect scientific judgment.

Scientists have their own specific traditions and values, which they learn from a mentor, older colleague, or other role model. This includes not only the avoidance of dishonesty or fraud but also giving appropriate credit to competitors if they have priority in making a discovery. A good scientist will tenaciously defend his own priority claims, but at the same time he is usually anxious to please the leaders in his field and will sometimes follow their authority even when he should be more critical.

Any cheating or manufacturing of data is discovered sooner or later and is the end of a career; for that reason alone, fraud is not a viable option in science. Inconsistency is perhaps a more widespread failing; there is probably no scientist who entirely escapes it. Charles Lyell, whose *Principles of Geology* influenced Darwin's thinking, preached uniformitarianism, but it struck even some of his contemporaries how nonuniformitarian was his own theory of the origin of new species. Darwin himself was also capable of inconsistency; he applied population thinking when explaining adaptation by natural selection, but he employed typological language in some of his discussions of speciation. Lamarck proclaimed loudly that he was a strict mechanist, endeavoring to explain everything in terms of mechanical causes and forces, and yet his discussion of inevitable perfection through evolutionary change strikes the modern reader as a subconscious adherence to a (nonmechanistic) perfecting principle. None of Darwin's adherents stressed natural selection more forcefully than A. R. Wallace, but when it came to applying it to man, Wallace "chickened out."

Some flaws in the findings and hypotheses of scientists are clearly induced by wishful thinking. When an early investigator found 48 chromosomes in the human species, this discovery was subsequently confirmed by numerous other investigators because that is the number they expected to find. The correct number (46) was not established until three different new techniques had been introduced.

Recognizing that error and inconsistency are widespread in science, Karl Popper in 1981 proposed a set of professional ethics for the scientist. The first principle is that there is no authority; scientific inferences go well beyond what any one person can master, including specialists. Second, all scientists at all times commit errors; they seem to be unavoidable. One should search for errors, analyze them when found, and learn from them; it is an unforgivable sin to conceal errors. Third, while such self-criticism is important, it must be supplemented by criticism by others, who can help discover and correct one's errors. In order to be able to learn from one's errors, one must acknowledge them when others call attention to them. And finally, one always must be aware of one's own errors when calling attention to those of others.

The major reward of a scientist is his prestige among his peers. This prestige depends on such factors as how many important discoveries he has made and what his contribution to the conceptual structure of his discipline has been. Why are priority and recognition by peers so important to most scientists? Why do a few scientists try to denigrate their peers (or competitors)? How is a scientist rewarded for achievements? What is the relationship of scientists to one another, and the relation of scientists to the rest of society? All such questions have been asked by researchers in the sociology of science, most importantly by Robert Merton, who virtually founded the discipline. As Merton has shown, much modern science is done by research groups, and alliances are often formed under the flag of certain dogmas.[8] But despite a certain degree of dissension in science, what impresses outsiders most is the remarkable consensus among scientists in the last half of the twentieth century.

This consensus is particularly well reflected in the internationality of science. English is rapidly becoming the lingua franca of science, and in certain countries, such as Scandinavia, Germany, and France, prominent scientific journals have adopted English names and publish primarily English-language articles. A scientist traveling to another country, even an American visiting Russia or Japan, feels quite at home when in the company of colleagues from those countries. Numerous articles are published these days in scientific journals in which the coauthors are from different countries. One hundred years ago scientific papers and books very often had a distinctly national flavor, but this is becoming rarer all the time.

All scientists who reach worthwhile goals tend to be ambitious and hard-working. There is no such thing as a 9-to-5 scientist. Many work 15 to 17 hours a day, at least during certain periods of their career. Yet most of them have broad interests, as is evident from their biographies; quite a number of scientists are amateur musicians, for instance. In other respects scientists are as variable a lot as any human group. Some are extroverts, others shy introverts. Some are exceedingly prolific, while others concentrate on the production of a few major books or papers. I do not think that there is a definite temperament or personality that one could identify as the typical scientist.

Traditionally one became a biologist either through a medical education or by growing up as a young naturalist. At present it is much more common for a youngster to become excited about the life sciences through the media, particularly nature films on television, visits to a museum (often the dinosaur hall), or an inspiring teacher. There are also thousands of young bird watchers, some of whom will become professional biologists (as I did). The most important ingredient is a fascination with the wonders of living creatures. And this stays with most biologists for their entire life. They never lose the excitement of scientific discovery, whether empirical or theoretical, nor the love of chasing after new ideas, new insights, new organisms. And so much in biology has a direct bearing on one's own circumstances and personal values. Being a biologist does not mean having a job; it means choosing a way of life.[9]