SCIENTIFIC LITERACY AND THE TEACHING OF EVOLUTION*

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My professional practice involves four related activities. (1) Scientific research in genetics and biological evolution, including such issues as the molecular clock of evolution, gene expression, natural selection, and the evolution of parasitic protozoa, such as *Plasmodium*, the agent of malaria, and *Trypanosoma cruzi*, the agent of Chagas disease, research relevant for the development of vaccines and medicines. (2) University teaching, mostly to undergraduates, including a very successful program that prepares "minority" (mostly Hispanic) students for Ph.D. research and teaching careers. (3) Writing scientific research papers and books, but also numerous articles and several books addressed to the general public. (4) Public lectures, some technical in universities and to other scientific communities, and also frequent speaking engagements addressed to general audiences, in universities, educational associations, religious institutions, and various sorts of forums, in the United States and abroad, from America Latina to Europe and elsewhere, including such countries as Israel and Turkey in the Middle East and Japan and China in the Far East.

In this essay, I will limit the discussion to my efforts addressed to the general public, through writings and speaking engagements, activities that I consider most important, because of what I perceive to be an urgent pursuit: the scientific education of the general public.

The case I want first to make is that scientific literacy, understood as an everyday working knowledge of science, is as necessary as reading and writing (literacy in the commonly understood sense) for a satisfactory way of life in the modern world. Scientific literacy is necessary for there being a capable work force, for the economic and health well-being of the social fabric and of every person, and for the exercise of participatory democracy.

I should make clear that by "scientific literacy" I do not mean detailed knowledge of scientific constructs, such as it is conveyed in textbooks of physics, chemistry, physiology, or genetics. I rather mean a comprehension of what might be called the scientific approach, or the scientific way

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of knowing, or even the scientific method. This comprehension requires that specific scientific knowledge be held, but this need not be ample or detailed, nor extensive through the disciplines or profound. In this sense, a scientifically literate person would know that astrology is not science, that children are not born with stronger muscles just because the parents exercise in the gym, and that humans evolved from nonhuman ancestors, yet there is no expectation that a scientifically literate person would know the definition of angular momentum or that the expression of DNA is mediated by transfer-RNA molecules, or to know that our hominin ancestors include *Homo habilis* and *Homo erectus*.

To be scientifically literate implies that whether or not a person endorses a government's program for water fluoridation or for building a nuclear power plant is not a decision based on the prejudice that all tampering with natural resources is harmful (or, at the other extreme, unambiguously beneficial), nor on the ignorance that decisions involve trade-offs, as may exist between a nuclear and a coal-fueled power plant. To be scientifically literate also implies that parents should expect their children to be taught in school about biological evolution and not that humans were created some ten thousand years ago.

UNESCO has defined literacy as an individual's ability to "read and write a short simple statement on his everyday life." With the phrase "scientifically literate" I do not intend to mean that a person must be learned in matters of science, nor I mean either that it suffices that a person be able to read and write. I rather mean something more like what has recently become known as "functional literacy," defined as the ability to comprehend what is read or written to an extent sufficient to perform adequately in society, whether to communicate with individuals, to further one's own economic or other interests, or to participate in the democratic way of life. Scientific literacy implies this functionality: the ability to respond to the technical issues that pervade our daily lives and the world of political action in a meaningful way.

There is universal need for scientific literacy. I will support this claim with arguments derived from two increasing demands of modern nations. First is the need for a technically trained labor force. Second is the requirement that citizens at large pass judgment on the promises and actions of their governments and on the claims of advertisers of consumer goods.

In the *Preface to Science in the National Interest*, a document published by the U.S. President's Executive Office, President Bill Clinton wrote that "Technology—the engine of economic growth—creates jobs, builds new industries, and improves our standard of living. Science fuels technology's engine." I would add that the cascade of causal agencies proposed by Clinton: Science→Technology→Economic Growth is supported by the strong correlation between the size of the investment that a nation makes

in science and technology research (assessed as the fraction of the country's GDP invested in R&D) and the standard of living and other measures of economic well-being that predominate in that nation.

The productive sector of the economy of any industrial nation demands a labor force that is scientifically literate. Thus, a country's economic well-being depends on the existence of high levels of scientific and technical literacy. Scientific and engineering breakthroughs are at the base of industrial productivity. Anyhow, economic and industrial development more immediately comes from adaptation of scientific ideas: new manufacturing materials and processes, including vaccines and curative drugs, advances in productivity and performance of workers, quality control of products, and consumer appeal and marketing. Economic development depends on the scientists and engineers who discover and invent, and on those who develop these innovations. But the successful implementation of the innovations depends on there being cadres of educated workers, skilled in the management of machinery, computers, control centers, quantitative information, and materials.

The workers required by modern industries have to understand technologically complex instructions in order to operate equipment and communicate and cooperate with each other in tasks that are far from purely repetitive. The acquisition of the necessary skills calls for a labor force that is scientifically literate in the sense I have explained. Moreover, the need as well as the benefits of scientific literacy extends beyond industry to other sectors of economic activity, such as agriculture and medicine. The greatly increased agricultural productivity of recent decades in countries such as the United States is largely attributable to the introduction and practice of modern farming practices and the use of efficient machinery that requires skilled operators.

Scientific literacy is also required for informed public involvement in the political and public life of a nation, including the teaching programs in the public schools. Information about technological and scientific matters is required by an increasingly large portion of the decisions made at the highest levels of government. Whether or not a highway system will be developed, and where and how; how to decide between the development of fuel-fired, hydrologic or nuclear sources of energy; how to protect and improve the water supply and air quality; the exploitation of mineral or marine resources; the preservation and commercial use of forests, rivers and coasts are among the numerous political decisions that cannot be wisely made without scientific and technological knowledge. The decision makers need to rely on policy advisers that are scientifically and technologically qualified for adequately briefing government officials and other decision makers on these sorts of issues. Besides, the decision makers themselves need to be scientifically literate in order to interpret, evaluate,

and use the experts' advice for making policy decisions and implementing them out through the political process. Democratically elected legislators and government officials are the representatives and must take responsibility for their decisions, rather than simply delegate them to the experts.

The goal of scientific literacy requires that meaningful science education be imparted in the schools. Science education should reach *all* students. Science education in the primary and secondary schools must fulfill several objectives. It must prepare the students that will go on to study science and engineering in technical schools, colleges, and universities and become the scientists and engineers that occupy critical positions in the industrial and economic development of modern nations. The schools must prepare as well the work force demanded by science-based industries and by the increasingly numerous enterprises that also require technically-skilled labor. Finally, the schools must accomplish the goal of preparing people for participatory citizenship, which requires as a minimum some understanding of the nature of scientific knowledge for individuals to make personal decisions that affect their day-to-day living as well as their participation in the body politic. These broad goals make it imperative that science education be started in the early school grades and continued through all years of mandatory education.

In virtually every nation there is dissatisfaction with the scientific education imparted in schools. Scientists and science educators have a lot to account for. The lack of scientific education, even of the most basic kind, in the United States is appalling; or dreadful if we take into account that our world is becoming increasingly technological and that economic prosperity and jobs depend on a scientifically literate citizenry. That is why I dedicate so much of my time to writing for the general public and to public speaking. Although I often broach other topics, my most frequent subject concerns biological evolution, including human origins.

According to a Gallup poll of 1 016 United States adults, taken in November 2004, 45 per cent of those surveyed favored the statement that "God created human beings in their present form within the last 10 000 years," 38 per cent favored that "Man developed over millions of years, but God guided the process," and 13 per cent that "Man developed over millions of years form less advanced life forms." Teaching creationism rather than evolution in the schools is favored by a large number of American citizens. In a CNN/*USA Today* Gallup poll of 1 001 adults conducted in March 2005, 76 per cent would not "be upset if public schools in [their] community taught creationism," but only 63 per cent would not "be upset if the schools taught evolution." Only 22 per cent would be upset if creationism would be taught, while 34 per cent would be upset if evolution would be taught. Other polls yield similar statistics. There can be no doubt that a crucial link is missing in the United States educational system: scientific literacy.

On January 4, 2008, the National Academy of Sciences (NAS) published *Science, Evolution, and Creationism*, which was prepared by a committee of the NAS that I chaired, as an effort to counteract the widening exertions of antievolutionists seeking to eliminate from public schools the teaching of evolution, or at least, to "balance" it by also teaching creationism and intelligent design. *Science, Evolution, and Creationism* is the third edition of *Science and Creationism*, published in 1984, but sufficiently modified to deserve a new title. A second edition of *Science and Creationism* was published in 1999. I also chaired the NAS committee that prepared this earlier document.

Science and Creationism was written in response to statutes passed by the legislatures of the states of Arkansas, first, and Louisiana, shortly thereafter, that required that "creation science" be taught in the public schools together with evolution. The Louisiana "Creation Act" was appealed all the way to the United States Supreme Court, which in 1987 (*Edwards v. Aguilard*) concluded that the Act's "primary purpose was to change the public school science curriculum to provide persuasive advantage to a particular religious doctrine that rejects the factual basis of evolution in its entirety. Thus, the Act is designed either to promote the theory of creation science that embodies a particular religious tenet or to prohibit the teaching of a scientific theory disfavored by certain religious sects. In either case, the Act violates the First Amendment." *Science and Creationism* was made part of an "amicus brief" submitted to the Supreme Court in *Edwards v. Aguilard* by the NAS, with the endorsement of the American Association for the Advancement of Science and other organizations.

In the 1990s, several authors schemed a new tactic to introduce creationism in the schools, or alternatively to remove the teaching of evolution, by reviving the old "argument from design," under the moniker of Intelligent Design Theory (ID). The argument from design for the existence of God, based on the complex organization of living things, was elaborated by English clergyman William Paley in his *Natural Theology*, published in 1802. Paley's argument from design is two-tined. The first prong asserts that humans, as well as all sorts of organisms, in their wholes, in their parts, and in their relations to one another and to their environment, cannot have come about by chance, but rather manifest to have been designed for serving certain functions and for certain ways of life. The second prong of the argument is that only an omnipotent Creator could account for the perfection and functional design of organisms. The new advocates of ID modified the second prong of the argument by referring to an unspecified "intelligent designer," thus avoiding explicit reference to God, so that the argument from design would not necessarily have religious connotations, and thus could be taught in the public schools as an alternative to evolution. This hypocritical subterfuge amounts to nothing else than a charade. On December 20, 2005, John E. Jones III, Federal Judge for the Middle

District of Pennsylvania, issued a 130-page-long decision (*Kitzmiller v. Dover Area School District*) declaring that "The overwhelming evidence at trial established that ID is a religious view, a mere re-labeling of creationism, and not a scientific theory ... ID is not supported by any peer-reviewed research, data, or publications."

Science, Evolution, and Creationism consists of three main chapters. The first chapter briefly describes the process of evolution and the nature of science in contrast to other forms of knowledge. The second chapter surveys the scientific evidence that supports evolution from diverse disciplines that include astronomy, paleontology, comparative anatomy, biogeography, molecular biology, genetics, and anthropology. The third chapter examines intelligent design and other creationist perspectives so as to point out the scientific and legal reasons against teaching creationism in public school science classes. The text concludes with a selection of frequently asked questions and additional readings.

There is a need for students, as well as for the general public, to know about biological evolution. Evolution is the central organizing principle of modern biology. In 1973, the eminent evolutionist Theodosius Dobzhansky famously asserted that "nothing in biology makes sense except in the light of evolution." Evolution provides a scientific explanation for why there are so many different kinds of organisms on Earth and gives an account of their similarities and differences (morphological, physiological, and genetic). It accounts for the appearance of humans on Earth and reveals our species' biological connections with other living things. It provides an understanding of the constantly evolving bacteria and viruses, and enables the development of effective new ways to protect ourselves against the diseases they cause. Evolution has made possible improvements in agriculture and medicine, and has been applied in many fields outside biology, including forensics and software engineering; it has stimulated chemists, for example, to use the principles of natural selection for developing new molecules with specific functions.

Biological evolution is part of a compelling historical narrative that scientists have constructed over the last few centuries. The narrative begins with the formation of the universe, the solar system, and the Earth, where conditions occur suitable for life to evolve. There are theories that seek to account for how life originated on Earth, but none of them has gathered enough supporting evidence to be generally accepted by scientists. But natural selection, discovered by Darwin, has been convincingly demonstrated as the process that accounts for the adaptive configuration and function of organisms, for their "design." Darwin is often credited with providing compelling evidence that evolution has occurred, but Darwin's greatest contribution to science is that he discovered natural selection, the process that accounts for the design of organisms, their

wonderful adaptations to survive and reproduce in the environments where they live: wings for flying, legs for running, eyes to see, and kidneys that regulate the composition of the blood.

Religious authors, and scientists as well, have written eloquently about their awe and wonder at the history of the universe and of life on this planet, explaining that they see no conflict between the evidence for evolution and their belief in God. Authorities of diverse religious denominations have issued statements affirming the compatibility between the tenets of their faith and the acceptance of biological evolution. Science and religion concern different aspects of the human experience. Scientific explanations are based on evidence drawn from examining the natural world and rely exclusively on natural processes to account for natural phenomena. Scientific explanations are subject to empirical tests by means of observation and experimentation, and are subject to the possibility of modification and rejection. Religious faith, in contrast, does not depend on empirical tests, nor is it subject to the possibility of rejection based on empirical evidence.

Nevertheless, many people of faith have questions about biological evolution, because they have been told that the scientific understanding of evolution is incorrect or at least doubtful, and that accepting evolution is not compatible with their religious beliefs. That is why so often I speak and write about evolution for the general public. The NAS document, *Science, Evolution, and Creationism* also speaks to these questions. It is written to serve as a source of information and as a resource for people who find themselves embroiled in debates about evolution. It should be helpful to "school board members, science teachers and other education leaders, policy makers, legal scholars, and others in the community who are committed to providing students with quality science education." Moreover, as stated in the preface, *Science, Evolution, and Creationism* "is also directed to the broader audience of high-school and college students as well as adults who wish to become more familiar with the many strands of evidence supporting evolution and to understand why evolution is both a fact and a process that accounts for the diversity of life on Earth." Our educational system and society as a whole are best served when we teach science, not religious faith, in science classrooms. That is but one step in the efforts to fill in the missing link of science literacy.

*In this essay I have made extensive use of previous publications of mine: "Spotlight. The missing link: scientific literacy," *The Systematist* 30:27-32, 2008; "Introductory essay: The case for scientific literacy," in H. Moore, ed., *World Science Report, 1996* (UNESCO Publishing: Paris), pp. 1-5; and the book, *Darwin's Gift to Science and Religion* (Joseph Henry Press: Washington, DC), 2007.