

EVOLUTION IN PERSPECTIVE

THE SCIENCE TEACHER'S COMPENDIUM



Rodger W. Bybee, Editor

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FOREWORD

“Turn on” the evolution lightbulb



As a high school science teacher, I was always fascinated with my students' ability to “turn on” and “turn off” the material they wanted to learn. They were always selective in determining whether the information would be important to them one day and whether they wanted to spend time learning it. I never had to worry, however, about getting their attention when the word “evolution” appeared in the text, a video, or the activities. The majority of students immediately conjured up a vision of something forbidden, controversial, and downright wrong. I grew to expect their strong reactions to the word itself, their misconceptions about evolution and the word “theory,” and their attentiveness during the learning process as we explored yearlong themes related to evolution and change. Some students changed their attitudes toward evolution as they inquired into the processes of change, but I also know that many students did not. Students always wrote at the end of the year about the evidence for evolution, which we had slowly and consistently developed throughout the course. I'll never forget one short essay that stated, “This was a lot of fun, but I don't believe any of it.”

Teaching evolution does not just require aligning our curriculum to the National Science Education Standards (NSES) or putting the material in a textbook or unit on change and adaptation. Teaching evolution requires us to develop a whole way of thinking among our student population. Understanding the nature of science is fundamental to understanding evolution and understanding theories. We can build our case for evolution throughout the school year, but we cannot change the way our students think about evolution without focusing on the nature of science and working to dispel myths about the word “theory” itself.

Over the past five years, *The Science Teacher*, NSTA's secondary science journal, has reviewed and published original manuscripts that addressed this very issue. At first we concentrated on manuscripts demonstrating classroom activities for teachers to teach evolution. We were more concerned about student attitudes on the topic than we were about the science educators who taught the classes. But one detailed research study changed our focus on evolution, when Jeffrey Weld and Jill C. McNew submitted their unsolicited manuscript, “Attitudes toward Evolution,” in the summer of 1999. Observing a

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“polar discord” among preservice teachers on the topic of creationism and evolution, the authors pursued a study to determine how much variation exists among teachers regarding this “controversial unifying concept” (Weld and McNew, December 1999, 27).

Their findings had national implications and revealed startling statistics. From Oklahoma, where they found 33 percent of science teachers placed little or no emphasis on evolution, to Illinois, where 30 percent believed both creationism and evolution should be taught in high school biology classes, statistics clearly demonstrated that national standards for teaching evolution theory were not being met.

While evolution is taught as an integral part of the science curriculum at the university level, secondary courses often are heavily influenced by personal views, and parental, student, and administrative pressure. Secondary textbooks, old and outdated in many classrooms, do not reflect current research and tend to place evolution in its own chapter, separate from all the concepts with which it intertwines. Secondary science courses, despite great strides in developing integrated curricula, usually still contain short, segmented units rather than an emphasis on overall concepts and themes central to science. Finding a textbook demonstrating the fundamental influence of evolution in all aspects of biological and physical science for the seventh grade, for instance—and then getting it adopted by the school district—is a huge challenge.

Textbook designers faced a real dilemma as well. While national standards cite evolution as a fundamental concept to the teaching of science, state standards began to erode the terminology and emphasis on evolution. Some states removed the word altogether, often referring to “adaptation” or “change.”

Teachers were left in the middle of the debate on whether to teach to national or state science standards. Required to teach to state stan-

dards rather than national standards in many districts, teachers also faced a narrowing curriculum that emphasized facts and content rather than the overall picture of the nature of science. Pressure mounted in subsequent years to follow the textbook and not vary from the mandated curriculum, and the vicious cycle continued.

But the real significance of the Weld and McNew study lies in the background information they gathered. They found “no difference between the emphasis placed on evolution by males or females, new teachers versus veterans, rural versus urban and suburban teachers, or those with bachelor’s vs. master’s degrees” when teaching evolution in public school biology. Instead they found that the factors most important to identifying teacher’s philosophies toward emphasizing evolution in their secondary classrooms are:

- Coursework and independent study in the nature or philosophy of science,
- Membership in professional science teacher organizations, and
- Use of national standards in guiding their practice (Weld and McNew, Dec. 1999, 31).

Indeed Weld and McNew’s findings were significant and led us to emphasize the role of secondary science teachers in addressing evolution in terms of the nature and philosophy of science. Over the next several years, we published articles by scientists, professors, and classroom teachers who addressed evolution and its role in understanding the nature of science. Submitted manuscripts were peer reviewed and aligned with the objectives outlined in the *National Science Education Standards* (NRC, 1996), the American Association for the Advancement of Science (AAAS) *Benchmarks for Science Literacy* (1993), and NSTA’s position statement *The Teaching of Evolution* (1997). This compendium is a result of that effort.

JANET L. GERKING
Field Editor
The Science Teacher

INTRODUCTION

EVOLUTION IN PERSPECTIVE

RODGER W. BYBEE

Science teachers have the opportunity to introduce students to one of the greatest intellectual achievements in history. I speak here, of course, about the theory of evolution in general and biological evolution in particular. They also have the responsibility to impart to their students an understanding of a scientific worldview and of the limits, possibilities, and dynamics of science as a way of knowing. Combining an understanding of the theory of evolution with an understanding of the nature of science is one way to think about the title of this compendium—*Evolution in Perspective*.

The articles in the compendium, selected to serve as resources for science teachers as they teach evolution, provide perspectives from scientific and educational leaders who understand evolution, the nature of science, and very importantly, the crucial role of science teaching. The articles equip science teachers with background information about evolution and the nature of science, the role of evidence, contemporary examples of evolution, and different perspectives that support the integrity of science and defend against assaults on the science curriculum. That said, however, teaching evolution is not without challenges.

Teaching evolution in perspective challenges educators to address continuing efforts to reduce the attention given to the topic of evolution in school science programs—or to eliminate it altogether. Science teachers face four critical challenges as they attempt to teach evolution. First, science teachers must introduce students to the scientific concepts of evolution together with, and as an integral part of, the nature of science. This calls for an examination of textbooks and teaching. Second, teachers must replace their defensive posture in the face of attacks from fundamentalist groups with constructive ap-

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proaches for teaching evolution. In the recent past, scientists and educators have expended considerable time and energy on the defensive—debating the ill-conceived, but often well-organized and articulate positions of creationists. Some states, schools, and teachers have acceded to the challenges of these groups by changing school science materials and programs in ways that undermine the integrity of science. To address this issue, science teachers must understand and teach the scientific theory of evolution. Third, closely related to the issue of teaching the theory of evolution is the need to understand and teach about inquiry and the nature of science. Finally, science teachers require the support of the broader scientific community if they are to meet these challenges.

TEXTBOOKS AND TEACHING

We would do well to begin with an examination of science textbooks. For the most part, our textbooks read like a collection of facts—small revealed truths that miraculously appear on pages without explanation. Students have no opportunity to learn how these scientific facts came to be or why they are different from any other way of explaining the natural world. At best, scientific processes are presented as lists of words such as “observation,” “hypothesis,” “inference,” and so on. At worst, students memorize the scientific method as a five- or six-step procedure. Is it any wonder that students and adults don’t understand inquiry and the nature of science? These are some general concerns about science textbooks. Specifically, how do textbooks address evolution and the nature of science?

Some good news can be reported about the topic of evolution in science textbooks. Although there remains a lingering impact of the 1925 Scopes trial on high school biology textbooks, mainstream biology textbooks include evolution. I am very pleased that history records the fact that the three textbooks produced in the early

1960s by the organization I direct, the Biological Sciences Curriculum Study (BSCS), reintroduced evolution as the unifying theme of biology. From 1925 until 1963 there had been a steady decline in the coverage of evolution in high school textbooks. BSCS put evolution back in the high school textbooks (Moore, 2001; Rudolph, 2002). BSCS continues this tradition with a new program, *BSCS Biology: A Human Approach* (BSCS, 2003), in which the first major unit is “Evolution: Patterns and Products of Change in Living Systems.” Concerning textbooks, I think it reasonable to say that developers and publishers have responded to the need to include evolution as a topic. How it is presented remains an issue, and attention to inquiry and the nature of science continues to receive only marginal emphasis.

What about science teaching? Unfortunately, many science teachers avoid teaching the theory of evolution and using the inquiry approach, and the nature of science has little importance in today’s science curricula. Teaching science in a manner that requires students to memorize facts and technical vocabulary does not help them understand major conceptual ideas such as evolution (Bransford, Brown, and Cocking, 2000; Bybee, 2002). To the degree some teach science in this manner, we will have to confront students’ lack of understanding of science in general and evolution in particular. Many students never really learn that science is a way of explaining the natural world and a discipline characterized by careful observation and experimentation in which explanations are tentative, are open to skeptical review, and can change based on evidence. Moreover, they never experience the excitement and wonder of science—another outcome of an inadequate science education.

It is no mystery then that citizens confronting declarations and questions such as “Evolution is never observed,” “Where are the missing links?” “Science cannot explain...,” and “Evolution is only a theory” are confused about the critical distinction between science and re-

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ligion and, subsequently, about support for science in the school curriculum. Take the last example: “Evolution is only a theory.” In everyday discussions of nonscientific issues, individuals often say, “I have a theory about that.” At best they mean “I have a personal explanation,” and often they mean “I have an opinion.” Seldom do they mean “I have evidence supporting my position.” So, when confronted with the assertion that “evolution is only a theory,” and the emphasis is on “only,” the average person assumes that creationists’ ideas have equal *scientific* standing with the theory of descent with modification. This issue is further confused because most individuals do not understand the relationship of scientific facts to theories. So they assume that facts are true and theories are only educated guesses. They simply do not understand the nature of science because they have not had an adequate science education.

TEACHING THE SCIENTIFIC THEORY OF EVOLUTION

The cultural contributions of science include a set of major ideas about how the natural world works. The particulate model of matter, the germ theory of infectious disease, and the gene model of inheritance are all examples of science’s intellectual contributions to culture. The theory of biological evolution is among the most powerful and significant scientific contributions of the nineteenth and twentieth centuries (Mayr, 2000). This said, my earlier discussions of textbooks and teaching points out a fundamental educational problem. When teachers focus on numerous technical terms, students lose sight of the major idea. Metaphorically, students are examining seedlings and they fail to see the trees, much less the forest. With the focus we have in most current textbooks, the low levels of scientific literacy should not at all surprise us.

Science teachers can, for example, teach the theory of evolution using the approach of historical case study. This narrative form, or the

explanatory story, provides students with a unique form of science education, and it affords science teachers the opportunity to integrate the nature of science and evolutionary theory. Explanations related to the theme of evolution have a long and very rich history, and they center on interesting, often compelling, questions such as “Why are there so many different kinds of plants and animals?” and “How can the similarities among organisms be explained?” If educators built a portion of the science curriculum on the historical development of explanations to such questions, they would help to make the theory of evolution coherent and meaningful for students, equipping them to counter the continuous assaults by creationists.

The narrative approach can also help students understand the historical and scientific development of the theory of evolution. This approach, which emphasizes interrelated facts, propositions, inferences, and the human struggle to develop the strong explanations that form a theory such as evolution, provides an alternative to the memorization of details and single propositions. It also illustrates how theories are formulated and developed, thus helping students understand one of the most important activities in the growth of scientific knowledge (Lewis, 1988).

From a science teaching point of view, presentation of the formulation and development of the theory of evolution provides a logical structure for established knowledge, reveals logical relationships among the facts and inferences of a theory, and demonstrates the role that human imagination plays in the processes of science. Teachers can introduce students to a set of postulates and then continually pose questions about evidence supporting the postulates, the development of explanation, the ability to predict, and the lines of reasoning that connect the evidence, explanations, and predictions (Lewis, 1987).

In *One Long Argument*, Ernst Mayr (1991) provides an example of the relationship between em-

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FIGURE 1

Darwin's Theory of Evolution by Natural Selection

Fact 1: All species have such great potential to produce large numbers of offspring that their population size would increase exponentially if all individuals that are born survived and reproduced successfully.

Fact 2: Except for seasonal fluctuations, most populations are normally stable in size.

Fact 3: Natural resources are limited, and in a stable environment they remain relatively constant.

Inference 1: Because more individuals are produced than the available resources can support, and the population size remains stable, there must be a fierce struggle for existence among the individuals of a population. This results in the survival of only a part, often a very small part, of the offspring of each generation.

Fact 4: No two individuals in a population of organisms are exactly the same; rather, each population displays enormous variation in characteristics.

Fact 5: Much of this variation can be inherited.

Inference 2: Survival in the struggle for existence is not random but depends in part on the characteristics that the surviving individuals inherited. This unequal survival is a process of natural selection that favors individuals with characteristics that best fit them in their environment.

Inference 3: Through many generations, this process of natural selection will lead to a continuing, gradual change in populations—that is, to evolution and the production of new species.

Based on a description by Ernst Mayr. 1991. *One Long Argument*. Cambridge, MA: Harvard University Press.

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pirical observations (facts) and the inferences that form a vital aspect for the scientific endeavor. Figure 1 presents an example of the logic, reasoning, and imagination that go into formulating connections between evidence and scientific explanations.

The recommendations expressed in this section are not new (Lewis, 1986). Further, there are excellent resources, for example, John A. Moore's *Science as a Way of Knowing* (1993), Ernst Mayr's *One Long Argument* (1991) and *This Is Biology* (1997), and I. B. Cohen's *Revolution in Science* (1985), that provide background and knowledge for the science teacher. In addition, science teachers will find *Teaching about Evolution and the Nature of Science* (National Academy of Sciences, 1998) a valuable resource.

TEACHING INQUIRY AND THE NATURE OF SCIENCE

When asked for a definition of science, most science teachers express the complementary ideas that science is both a body of knowledge and a process. In the course of such discussions few disagree with an assertion made by the late Carl Sagan (1993) that "Science is a way of thinking much more than it is a body of knowledge." Yet, as pointed out in the prior section, science textbooks and teaching give significantly more emphasis to science as a body of knowledge than to science as a way of thinking. The emergence of modern science in the late sixteenth and early seventeenth centuries was primarily due to the acceptance of new ways of thinking and explaining the natural world.

How does one characterize the basic elements of a scientific way of thinking? Briefly, a scientific explanation of nature must be based on empirical evidence from observations and experiments. Proposed explanations about how the world works must be tested against empirical evidence from nature. The scientific way of thinking stands in contrast to other ways of explaining nature—for example, religious doctrine or the acceptance of statements by arbitrary au-

thority. After the scientific revolution such approaches to explaining the natural world were no longer satisfactory. Explanations had to be subject to confirmation by empirical evidence. For example, Galileo's observations of heavenly bodies confirmed Copernicus's heliocentric explanations of planetary motion. Since the emergence of modern science, our understanding of the natural world has been based on current explanations and on the interaction of human reasoning, imagination, and the empirical evidence of nature itself. One could reasonably argue that the scientific way of knowing also is among the great intellectual achievements. To emphasize points made earlier, students leave our schools without a clear understanding of the nature of scientific knowledge and the ways by which scientists claim to know about nature. Students may learn that science proceeds through a prescribed five-step method or through various laboratory procedures, but they do not learn about the processes of science. Thus, they lack a fundamental understanding of science. Teaching about inquiry and the nature of science could serve as a major countervailing force against those who propose that dogmatic, nonscientific explanations be included in the science curriculum.

SUPPORT FOR SCIENCE TEACHERS

Science teachers confront many challenges. In this introduction I have named several directly related to teaching the theory of evolution in perspective. Fortunately, however, support for teaching about evolution is available in a variety of forms.

National policy documents that address the content of school science programs clearly and directly promote the teaching of evolution. One document in particular provides both guidance for the content of school science programs and support for those who encounter challenges to scientific integrity and content of the science curriculum—the *National Science Education Stan-*

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dards (NRC, 1996). Here teachers will find significant support for the inclusion of evolution, by name, in school science programs. In addition, science teachers will find consistency between statements in this document and two publications produced by the American Association for the Advancement of Science (AAAS)—*Science for All Americans* (1989) and *Benchmarks for Science Literacy* (1993). *Science for All Americans* includes clear and succinct discussions of the evolution of life, the nature of science, and the diversity of life. *Benchmarks* contains similar sections and provides brief statements of what individuals should know about the respective categories. *Benchmarks* and *Standards* have many similarities, and overlap significantly in some science content areas (AAAS, 1996). Teachers of science can use the consistency displayed by these two major scientific organizations, the National Research Council and the American Association for the Advancement of Science, as support for teaching evolution and the history and nature of science.

Depending on the state, science teachers have varied support from state standards. A report released in 2000 described and gave grades on states' treatment of evolution in science standards (Lerner, 2000). About half (24) of the states received A or B. Particularly noteworthy were California, Connecticut, Indiana, New Jersey, North Carolina, Rhode Island, South Carolina, Delaware, Hawaii, and Pennsylvania. Unfortunately, 13 states received F or F-. So, depending on the state, science teachers may or may not have the support they need. Personally, I think this is a national embarrassment and a dereliction of responsibility by states receiving any grade less than an A.

Important professional organizations for science teachers, specifically the National Science Teachers Association (NSTA), the National Association of Biology Teachers (NABT), and the National Earth Science Teachers Association (NESTA) have position statements that support

the teaching of evolution. These position statements are complemented by those of scientific groups such as The National Academies, American Institute of Biological Sciences, American Geological Institute, American Association for the Advancement of Science, and other discipline specific groups.

I would be remiss if I did not mention the National Center for Science Education and the tireless work of Eugenie Scott and her colleagues. The various initiatives associated with creationism and intelligent design would have a much greater influence if it were not for Dr. Scott. Her support for science teachers is truly outstanding. Other individuals also have provided support—for example, Randy Moore, editor of *The American Biology Teacher*; Ken Miller, Brown University; Don Kennedy, Editor of the AAAS journal *Science*; and Bruce Alberts, president of the National Academy of Sciences, to mention a few.

CONCLUSION

In closing, I turn to this NSTA compendium. For some time NSTA has included articles on evolution in *The Science Teacher*, its journal for high school teachers. Publishing such articles, in my view, sends a clear and direct message of support to science teachers. I was honored when asked to recommend and organize articles dealing with evolution from past issues of *The Science Teacher*. Upon review I realized that the articles represented perspectives from scientists, science educators, and science teachers. This compendium represents some of the best contemporary scientific and educational thinking and presents evolution in perspectives that will be a resource and support for all science teachers.

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ARGUING FOR EVOLUTION

FRANCISCO J. AYALA



On August 11, 1999, the Kansas State Board of Education voted six to four to remove references to cosmology and evolution from the state's education standards and assessments. The board's decision does grave disservice to the students and teachers of the state of Kansas as well as to science and religion everywhere. Students need to study the empirical evidence and concepts central to scientific knowledge to become informed and responsible citizens and to acquire suitable job skills and professional training. The board's decision places Kansas's students at a competitive disadvantage in their education and job qualification and impairs the recruitment of capable and inspired teachers, who will abhor being inhibited from teaching their best knowledge.

EVOLUTION AND SCIENCE

Opponents to teaching the theory of evolution declare that it is only a theory and not a fact; and that science relies on observation, replication, and experimentation, but nobody has seen the origin of the universe or the evolution of species, nor have these events been replicated in the laboratory or by experiment.

When scientists talk about the "theory" of evolution, they use the word differently than people do in ordinary speech. In everyday speech, a theory is considered to be an imperfect fact, as in "I have a theory as to what caused the explosion of TWA flight 800." In science, however, a theory is based on a body of knowledge.

According to the theory of evolution, organisms are related by common descent. There is a multiplicity of species because organisms change from gen-

eration to generation, and different lineages change in different ways. Species that share a recent ancestor are therefore more similar than those with remote ancestors. Thus, humans and chimpanzees are, in configuration and genetic makeup, more similar to each other than they are to baboons or to elephants.

Scientists agree that the evolutionary origin of animals and plants is a scientific conclusion beyond reasonable doubt. They place it beside such established concepts as the roundness of the Earth, its rotation around the Sun, and the molecular composition of matter. That evolution has occurred, in other words, is a fact.

How is this factual claim compatible with the accepted view that science relies on observation, replication, and experimentation, even though nobody has observed the evolution of species, much less replicated it by experiment? What scientists observe are not the concepts or general conclusions of theories, but their consequences. Copernicus's heliocentric theory affirms that the Earth rotates around the Sun. Nobody has observed this phenomenon, but we accept it because of numerous confirmations of its predicted consequences. We accept that matter is made of atoms, even though nobody has seen them, because of corroborating observations and experiments in physics and chemistry. The same is true of the theory of evolution. For example, the claim that humans and chimpanzees are more closely related to each other than they are to baboons leads to the prediction that the DNA is more similar between humans and chimps than between chimps and baboons. To test this prediction, scientists select a particular gene, examine its DNA structure in each species, and thus corroborate the inference.

Holding strong religious beliefs does not preclude intelligent scientific thinking.

Experiments of this kind are replicated in a variety of ways to gain further confidence in the conclusion. And so it is for myriad predictions and inferences among all sorts of organisms.

Not every part of the theory of evolution is equally certain. Many aspects remain subject to research, discussion, and discovery. But uncertainty about these aspects does not cast doubt on the fact of evolution. Similarly, we do not know all the details about the configuration of the Rocky Mountains and how they came about, but this is no reason to doubt that the Rockies exist.

The theory of evolution needs to be taught in schools because nothing in biology makes sense without it. Modern biology has broken the genetic code, developed highly productive crops, and provided knowledge for improved health care. Students need to be properly trained in biology to improve their education, increase their chances for gainful employment, and enjoy a meaningful life in a technological world.

RELIGION AND SCIENCE

Does the teaching of evolution pose a threat to Christianity or to other religions? This question can be answered in two parts. I would first address those who profess a materialistic philosophy and seek to ground it in the theory of evolution and other scientific claims. They point out the great success of science in explaining the workings of the universe and claim there is no room for other kinds of explanations—no room for values, morality, or religion. We may grant these persons their right to think as they wish, but they have no warrant whatsoever to ground this materialistic philosophy in the achievements

of science. Science seeks material explanations for material processes, but it has nothing definitive to say about realities beyond its scope. Science is a way of acquiring knowledge about ourselves and the world around us, but it is not the only way. We acquire knowledge in many other ways, such as through literature, the arts, philosophical reflection, and religious experience. Scientific knowledge may enrich aesthetic and moral perceptions, but these subjects transcend science's realm.

Scientific knowledge cannot contradict religious beliefs, because science has nothing to say for or against religious realities or religious values. Many religious authorities have made this point. Catholic, Lutheran, and other Christian bishops have joined Jewish and other religious leaders in denying that the theory of evolution contradicts or threatens their religious beliefs.

There are, however, believers who see the theory of evolution and scientific cosmology as contrary to the creation narrative of the Book of Genesis. We may grant these believers their right to think this, just as at the other extreme of the spectrum we grant materialists their right to deny spiritual or religious values. But, as the counterpoint to what I said above, I will aver that Genesis is a book of religious revelations, not a textbook of astronomy or biology. Pope John Paul II has made the point: "The Bible speaks to us of the origins of the universe and its makeup, not in order to provide us with a scientific treatise, but in order to state the correct relationship of man with God and the universe. Sacred scripture wishes simply to declare that the world was created by God, and in order to teach this truth, it expresses itself in the terms of the cosmology in use at the time of the writer. The sacred book likewise wishes to tell men that the world was ... created for the service of man and the glory of God. Any other teaching about the origin and makeup of the universe is alien to the intentions of the Bible, which does not wish to teach how heaven was made but how one goes to heaven." St. Augustine had made the

point many centuries earlier: "In the matter of the shape of heaven the sacred writers did not want to teach men facts that would be of no avail for their salvation." (See note, p. 4.)

The point made by St. Augustine and the pope is that it is a blunder to mistake the Bible for an elementary textbook of astronomy, geology, and biology. Instead, it is possible to believe that God created the world while also accepting that the planets, mountains, plants, and animals came about, after the initial creation, by natural processes. I can believe that I am God's creature without denying that I developed from a single cell in my mother's womb by natural processes. This is the second part of my answer to the purported opposition between scientific conclusions and religious beliefs. They do not stand in contradiction; they concern different sorts of issues, belong to different realms of knowledge.

INTELLIGENT DESIGN?

There is one more point I wish to make in response to those who defend the special creation of the species on the grounds of their design, which they see as necessarily a product of divine intelligence. The point is that not only can natural selection account for the "design" of organisms but also it amounts to blasphemy to attribute it to God's special action.

Consider the human jaw. We have too many teeth for the jaw's size, so that wisdom teeth need to be removed, and orthodontists make a decent living straightening the other teeth. Would we want to blame God for such defective design? A human engineer could have done better. Evolution gives a good account of this imperfection. Brain size increased over time in our ancestors, and the remodeling of the skull to fit the larger brain entailed a reduction of the jaw. Evolution responds to the organism's needs through natural selection, not by optimal design, but by "tinkering" as it were, by slowly modifying existing structures. Consider now the birth canal of women, much too narrow for easy passage of

the infant's head, so that thousands upon thousands of babies die during delivery. Surely we do not want to blame God for this defective design or for the children's deaths. Science makes it understandable, a consequence of the evolutionary enlargement of our brain. Females of other animals do not experience this difficulty.

One more example: why are our arms and our legs, which are used for such different functions, made of the same materials, the same bones, muscles, and nerves, all arranged in the same overall pattern? Evolution makes sense of the anomaly. Our remote ancestors' forelimbs were legs. After our ancestors became bipedal and started using their forelimbs for functions other than walking, these became gradually modified, but retained their original composition and arrangement. Engineers start with raw materials and a design suited for a particular purpose; evolution can only modify what is already there. An engineer who designed cars and airplanes, or wings and wheels, using the same materials arranged in a similar pattern, would surely be fired. The defective design of organisms could be attributed to the gods of the ancient Greeks, Romans, and Egyptians, who fought with one another, made blunders, and were clumsy in their endeavors. But in my view, it is not compatible with a special action by the omniscient and omnipotent God of Judaism, Christianity, and Islam.

There is no need for warfare between science and religion. It is unfortunate that some would

deprive students of a proper scientific education on religious grounds, as it is unfortunate that some seek in science arguments to negate the legitimacy of religious beliefs.

BIOGRAPHICAL NOTE

John Paul II's quotation is from his address to the Pontifical Academy of Sciences on October 3, 1981. In his address to the Pontifical Academy of Sciences on October 22, 1996, he again deplored interpreting the Bible's teachings as scientific rather than religious, and said: "[N]ew knowledge has led us to realize that the theory of evolution is no longer a mere hypothesis. It is indeed remarkable that this theory has been progressively accepted by researchers, following a series of discoveries in various fields of knowledge. The convergence, neither sought nor fabricated, of the results of work that was conducted independently is in itself a significant argument in favor of this theory" (*L'Osservatore Romano*, 23 October 1996). St. Augustine's quotation is from *The Literal Meaning of Genesis*, book 2, chapter 9. In book 3, chapter 14, he makes the remarkable statement that many animal species were not present from the beginning, but appeared later "each according to its kind and with its special properties," as a result of a natural power "present from the beginning in all living bodies." One can surmise that Augustine would have found no conflict between the theory of evolution and the teachings of Genesis, which are the subject of his commentary.