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Countering Public Misconceptions about the Nature of Evolutionary Science

COUNTERING PUBLIC MISCONCEPTIONS ABOUT THE NATURE OF EVOLUTIONARY SCIENCE

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ABSTRACT

Challenges to modern evolutionary science are often rooted in fundamental misconceptions about the nature of science itself. Among the public, there is a widespread perception that the focus of science on natural cause-and-effect explanations is a thinly disguised effort to promote a godless worldview, rather than an inherent methodological limitation. Furthermore, the general public often view theories as merely unsubstantiated guesses, rather than as the unifying concepts that give our observations coherence and meaning. Theories within the historical sciences, in particular, are seen as being inherently untestable without an objective basis for assigning validity. Science for many is simply an encyclopedic accumulation of unchanging observational "facts." The dynamic nature of science with the continual revision of theoretical constructs becomes for them evidence of the fleeting validity of scientific "truth." The future of scientific literacy will depend on how we respond to these misconceptions as scientists and educators.

Key words: Nature of science, science teaching, evolution, methodological naturalism, scientific method, theory, philosophical naturalism, creationism, intelligent design

INTRODUCTION

Misunderstandings and fallacious understandings of the nature and limitations of science are widespread in our culture. They underlie much of the popular resistance to the conclusions of modern science, particularly historical sciences. Misunderstandings about the nature of science also lay at the foundation of most of the recent attacks on public science education by Intelligent Design proponents and traditional creationists. These efforts are expressions of deeply held, but entirely false, views of science that threaten many people's religious world views.

Although the popular ignorance of the conclusions of modern science has been widely recognized, the false understandings of the nature and practice of science are more fundamental and present a greater obstacle to scientific literacy. This is particularly true for the "historical sciences" – those sciences that deal with the reconstruction of the past. Those who oppose the current conclusions of the historical sciences commonly see scientific and theological descriptions of reality as being mutually exclusive and contradictory (1). A "warfare" view of science and faith is widely assumed. This view is supported by erroneous understandings of the nature of historical and theoretical science. A distorted understanding of the history of science also exacerbates this view.

Too many people in our society view science as simply the discovery of unchanging truths to be memorized and added to an encyclopedia of scientific knowledge. Theories are viewed as merely unsubstantiated guesses, rather than as the unifying concepts that give our observations coherence and meaning, provide us with a basis to make testable predictions, and ultimately to solve scientific problems. As a result, many people are unable to distinguish valid scientific conclusions from pseudoscience. The dynamic nature of science, with its continual revision of theoretical constructs, becomes evidence in the eyes of the public for mistrusting the validity of scientific "truth" and a basis for its outright rejection. Theories within the historical sciences, in particular, are seen as being inherently untestable and driven by a materialistic philosophical agenda (2).

The widespread public misperceptions of science are clear indicators that science educators have largely failed to communicate the processes by which scientific understandings of the natural world are obtained. Helping students to understand the nature and limitations of science is a fundamental part of science education. In recognition of this, the nature of science (NOS) is a prominent theme within all comprehensive science standards. This prominence is well articulated in documents such as Science for All Americans (3) and the National Science Education Standards (4). The NOS theme is also part of many state science standards, including those of Kansas.

The effective teaching of evolutionary science is also tied to the teachers' understanding of the nature of science. For example, studies of both college students and science teachers have shown a clear relationship between the lack of understanding of the nature of science and low acceptance of the theory of evolution (5). Furthermore, middle and high school teachers have not been adequately prepared to teach the NOS. Too often the NOS is left to implicit inference through students' science classroom experiences and reading, rather than being an explicit topic of instruction (6). This is especially the case when science is taught as a package of received factual knowledge to be learned, and where the emphasis is placed on the results of confirmatory laboratory assignments rather than on the dynamic process of inquiry itself.

Science teachers and educators need to be more aware of the popularly held erroneous understandings of science, and develop strategies to directly and effectively address them. Informing students and the larger public of how science really works, and what questions it does and does not address, is critical to combating the appeal of anti-evolutionary creationist arguments.

DISCUSSION

Misconceptions and obstacles to scientific literacy:

This paper will first present a number of the common public misconceptions of the nature of science, and briefly outline a response to each. This will be followed with some suggested educational remedies.

Science is a thinly disguised effort to promote a godless worldview.
Scientific and religious understandings of the origin and evolution of the universe, earth, and life are widely seen as being in tension if not outright opposition. Evolution in particular is seen as inherently atheistic and inseparably wedded to a worldview that denies God and objective morality. Evolutionary theory, often pejoratively referred to as "Darwinism," is also perceived as denying purpose and meaning. As a result, the science of evolution and the theology of creation have become in the minds of many two mutually exclusive explanations. Such dichotomous thinking is also consistent with our cultural preference for simplistic answers to complex problems.

For traditional creationists and most Intelligent Design (ID) supporters, the conviction that evolutionary theory and orthodox Christian faith are in irreconcilable conflict is fundamental. It is also a central part of the political strategy of the ID movement. As stated by Phillip Johnson, one of the founders and leaders of the ID movement: "The objective [of the Wedge Strategy] is to convince people that Darwinism is inherently atheistic, thus shifting the debate from creationism vs. evolution to the existence of God vs. the non-existence of God." (7)

The broader "warfare" view of science and faith owes much of its modern expression to a pair of widely influential 19th century works – John William Draper's History of the Conflict between Religion and Science (1874) and Andrew Dickson White's A History of the Warfare of Science with Theology in Christendom (1896). Such views have been perpetuated by simplistic and grossly inaccurate historical summaries. However, this warfare view has been thoroughly discredited by both theological and historical scholarship (8). Christian theologians (including evangelicals) have long recognized that a faithful reading of Scripture does not demand a young Earth, nor does it prohibit God's use of evolutionary mechanisms to accomplish God's creative will. Many evangelical Christians at the time of Darwin found no inherent conflict between evolutionary theory and scripture. In fact, several of the authors of the "Fundamentals" (the set of volumes that gave us the term "fundamentalist") accepted some form of evolutionary theory. One of these was B.B Warfield, a theologian who argued forcefully for Biblical inerrancy, and who accepted the validity of evolution as a scientific description of origins. Probably the most prominent advocate of evolutionary theory in America in Darwin's time was Asa Gray, a committed evangelical Christian (9). To the present day, Christian scientists and theologians have articulated this integration of evolutionary science and Christian faith within a broad range of theological traditions (10).

Although the conflict perspective continues to be promoted by some individuals within both the religious and scientific communities, its conflation of philosophical materialism or atheism with evolution must be rejected as philosophically, theologically, and historically false. As long as this false view is allowed to remain in students' minds, they (and by extension the general public) will be unable to accept the conclusions of science, no matter how well they are taught. The scientific enterprise is a limited way of knowing about the natural world. Scientific research proceeds by the search for chains of cause-and-effect, and confines itself to the investigation of "natural" entities and forces. This limitation of the scientific enterprise is sometimes referred to as "methodological naturalism." Science restricts itself to proximate causes, and the confirmation or denial of ultimate causes is beyond its capability. Science does not deny the existence of a Creator – it is simply silent on the existence or action of God. Methodological naturalism is not a prescriptive "rule", but simply describes what empirical inquiry is. It is certainly not a statement of the nature of cosmic reality. Science does not, and cannot, say that material things are all that exist, or all that matter. Science pursues truth within very narrow limits. Our most profound questions about the nature of reality (questions of meaning and purpose and morality), while they may arise from within science, are theological or philosophical in nature and their answers lie beyond the reach of science.

Some non-theists see God as an unnecessary addition to a scientific description of the universe, and therefore extend this to a philosophical exclusion. In fact, God is unnecessary, or rather irrelevant, for a scientific description, but a scientific description is not a complete description of reality. Scientific methodology excludes appeals to supernatural agents because it has no way to test for the action of such agents. To then use this methodological exclusion to support a philosophical exclusion is completely fallacious. That science does not make reference to God says nothing about whether or not God is actively involved in the physical universe or in people's lives.

One very important feature of the scientific enterprise is that it takes place within a multi-cultural and interfaith community of scholars. At a typical professional scientific meeting there will be participants from a wide range of nationalities, cultures, and religious traditions. Yet, those scholars can sit down together and productively discuss scientific questions, examine evidence and even reach consensus conclusions. They can do this because scientific knowledge is not tied to a particular religious or non-religious worldview – it is universally accessible. Any attempt to incorporate supernatural action into scientific description, or to declare that science is inherently atheistic, undermines this religious neutrality.

The methodological naturalism (MN) of science restricts the search for truth.

Many Intelligent Design (ID) advocates argue that MN arbitrarily and unjustifiably excludes supernatural agency from scientific explanation. They believe that this exclusion of God from scientific description unnecessarily restricts the search for truth. Phillip Johnson has made this a prominent focus of his arguments.

"We [members of the intelligent design movement] are opposed by persons who endorse methodological naturalism, a doctrine that insists that science must explain biological creation only by natural processes, meaning unintelligent processes. Reference to a creator or designer is relegated to the realm of religion, and ruled out of bounds in science regardless of the evidence." (11)

Note that MN is treated as a doctrine, a philosophical assumption, rather than a methodological limitation of scientific inquiry. In much of the ID and traditional creationist literature, MN is falsely presented as equivalent to philosophical naturalism or materialism. That is, the practice of science is seen as based on a philosophy that claims that the material universe is all that there is.

ID advocates believe that the exclusion of God from scientific description unnecessarily restricts the search for truth. It does nothing of the sort. If God acted in creation to bring about a particular structure in a way that broke causal chains, then science would simply conclude that: "There is presently no known series of cause-and-effect processes that can adequately account for this structure, and research will continue to search for such processes." Any statement beyond that requires the application of a particular religious worldview. Science cannot conclude "God did it." However, if God acted through a seamless series of cause-and-effect processes to bring about that structure, then the continuing search for such processes stimulated by the tentativeness and methodological naturalism of science may uncover those processes. Using an ID approach, the inference to "intelligent design" would be made, and any motivation for further research would end. Thus, ID runs the risk of making false conclusions, and prematurely terminating the search for cause-and-effect descriptions when one wasn't already at hand. Furthermore, how would a gap in our knowledge be filled unless there was a continued effort to search for possible "natural" causes? Thus even the verification of gaps requires research conducted using MN assumptions.

In both the 1999 and 2005 Kansas science standards controversies, a single word has been the focus of a great deal of attention. That single word is "natural." Scientists and science educators describe science as a human process of discovering natural explanations for the physical world around us. Creationists and ID supporters want to remove the word "natural" from the definition of science so that supernatural explanations can be admitted. However, an appeal to a supernatural agent does not provide any insight into how a particular event or process occurred. The intelligent design approach of "God did it" can explain anything, but doesn't provide the cause-and-effect understandings of physical phenomena that are the proper subject of science.

Supernatural action is a legitimate subject of scientific inquiry. Both traditional creationists and ID supporters have been seeking to have "non-natural" or supernatural action included as a legitimate part of scientific explanation. One way that this view is expressed is that science pursued under theistic assumptions must differ in its scientific conclusions from science as currently practiced. There is the strong desire to see scientific evidence for divine action, to have theistic arguments be part of science. William Dembski, a prominent ID advocate, has stated:

"... intelligent design is incompatible with what typically is meant by theistic evolution. Theistic evolution takes the Darwinian picture of the biological world and baptizes it, identifying this picture with the way God created life. When boiled down to its scientific content, however, theistic evolution is no different from atheistic evolution, treating only undirected processes in the origin and development of life." (12)

Note that this statement implies that "Darwinian" evolution is inherently atheistic and must be in conflict with a theistic perspective. It also accepts uncritically that evolution denies the possibility of divine guidance or purpose.

As previously argued, the methodology of science is incapable of investigating supernatural action. Even what scientific research is conducted by ID advocates is conducted using MN. The genetic research of Michael Behe, for example, is entirely consistent with standard science using a MN approach. There simply is no way to incorporate the actions of non-natural agents into a scientific research program. What ID proponents typically do is to overlay philosophical and religious understandings on scientific conclusions. They invest particular scientific observations with theological meaning. It is entirely appropriate for anyone to apply his or her religious and philosophical perspectives to interpreting science. Theists as much as atheists can, and should, work toward a comprehensive integrated worldview. However, that does not make such philosophical perspectives themselves scientific. It is no more appropriate to argue that science can conclude that "God did it," than to argue that science demonstrates that the natural world is all there is, or that natural process are divinely unguided and without ultimate purpose.

From the perspective of scientific inquiry, a supernatural agent is effectively a black box, and appeals to supernatural action are equivalent to appeals to ignorance. A supernatural agent is unconstrained by natural "laws" or the properties and capabilities of natural entities and forces. It can act in any way, and accomplish any conceivable end. As a result, appeals to such agents cannot provide any insight into understanding the mechanisms by which a particular observed or historical event occurred. Belief in the creative action of a supernatural agent does not answer the questions of "How?" "A miracle occurs here" is no more an answer to the question of "How?" than is "We don't know." The scientific community's passion is to understand the "Hows" of the natural world. It is the gaps in our current understanding of the natural world – those black boxes – that draw the attention of scientists and drive new discovery and new theoretical insights.

True science deals with proven facts.

Many people see science as an encyclopedic listing of unchanging facts. Since scientific "facts" are equated with "truth," once discovered they cannot change. This is an essentially static view of science, and very much at odds with the tentative nature of scientific conclusions and the dynamic process of scientific inquiry. It also elevates the discovery of observational "facts" as the fundamental objective of science. Theories on the other hand, are viewed as mere guesses and speculation. This is commonly expressed in phrases such as "Evolution is just a theory."

However, science is not the mastery of a body of unchanging scientific "facts", but a way of inquiring about our physical environment. It provides a way of understanding, explaining, and integrating our diverse observations of the natural world. Theories place our observations into an explanatory context and give them coherence and meaning. Although observations form the foundation of scientific description, serious theoretical inquiry is the essence of science. Observational "facts" by themselves are lifeless and do not yield understanding. Nothing could be more deadly to science than to divorce it from the unifying theories that give observations meaning. Theories also provide the predictions that suggest new observations and drive new discovery. Theories are the very essence of the scientific enterprise.

Scientific theories are not speculations or guesses but well-supported interpretations of the natural world. They are built up from many hypotheses that have survived repeated tests against new observations. However, no scientific theory can be proven in the sense of a mathematical or logical proof. Any accepted scientific theory is simply the best existing explanation for the observations already made, and rests on the continued success of the hypotheses that are generated from it. Science is a dynamic enterprise of understanding the natural processes operative in the universe. Scientists modify or even replace theories as new observations accumulate and improved explanatory models are developed. The very strength of scientific methodology is that ideas are subject to testing and verification.

The construction and testing of hypotheses is fundamental to scientific inquiry. Although different fields of scientific study have unique ways of approaching their subject, there are some basic elements that characterize scientific methodologies.

1) Observations are made of the natural world, whether directly or through the use of instruments.

2) Perceived patterns and regularities in these observations become the basis for proposing a hypothesis to explain them. This occurs within a set of already existing broader theoretical understandings.

3) A new set of observations not yet made is predicted deductively from the hypothesis.

4) The hypothesis can then be tested against these new observations. The original hypothesis may be supported, or the new observations may be found to be inconsistent or unexpected.

The above process may be followed very formally. However, it may also be followed in an informal, almost subconscious, way as a scientist generates and tests new ideas while working on a research problem.

Although hypotheses can be disproven by the methodology of science, they cannot be positively proved. Scientific conclusions are always tentative. However, the more the expectations generated by a hypothesis are confirmed, the more confidence the investigator has in that explanation. The success of hypotheses in turn lends additional support to the theories upon which those hypotheses rest.

There is no way to objectively select among "theories."

If a "theory" is understood simply as a guess or speculation, then one person's "theory" can be as good as another's. This is particularly true if scientific theories are viewed as resting more on philosophical bias than objective observations. Any person's idea becomes a "theory" with an equal claim to serious consideration. Arguments of any type and merit can then be seen as having equally valid claims to "truth." For the public, selecting between competing theories is more a matter of choosing authorities than critically evaluating scientific claims.

Scientists constructing scientific theories, and their component hypotheses, are influenced by philosophical, religious and cultural assumptions. The investigator(s) may even be unaware of some of these influences. However, those hypotheses are subject to test, and will not become widely held by the scientific community unless their predictions are fruitful. The source or inspiration for an idea is irrelevant to its utility as a scientific hypothesis. The validity of the idea must stand or fall on its own.

Theories change and are modified over time as new discoveries are made and new more productive interpretive frameworks are proposed. Some are ultimately rejected by the preponderance of practicing scientists, and others remain at the fringes provoking critical examination. How do we distinguish a good theory from a bad one? How do we establish relative confidence in theories? Criteria for a good scientific theory include: 1) explanatory power, or the ability to integrate and explain a wide range of observations, 2) predictive power, or testable expectations; 3) fruitfulness, or the ability to generate new questions and new directions of research; and 4) aesthetics (eg. beauty, simplicity, symmetry).

It is important that the process of evaluating a scientific theory (and its component hypotheses) takes place within a community of trained practicing scientists. The scientific enterprise is fundamentally conservative, and any new idea must meet the challenge of demonstrating a greater ability to explain and integrate current knowledge and predict future observations than its competitors. Scientists meet that challenge through diligent research, and by presenting the new ideas for criticism by the scientific community through professional meetings and publication in peer-reviewed science publications. Most new ideas do not survive this process. However, having passed through this process and won the consensus of the scientific community, a new idea is ready for widespread application in addressing outstanding questions in the field.

Biological evolution (descent with modification from a common ancestor), plate tectonics (the mobility and recycling of the Earth's crust), and the Big Bang theory are examples of extremely well substantiated theories that provide an interpretative framework for a vast amount of observational evidence. That is, they have great explanatory power. These powerful unifying theories continue to generate fruitful and testable hypotheses that drive new discovery.

The historical sciences are inherently untestable.

Creationists and ID supporters frequently claim that the historical sciences (cosmology, astronomy, geology, evolutionary biology, anthropology, archaeology) deal with unrepeatable events and are therefore not experimental. Furthermore, because past events and processes are not directly observable, theories of origins are deemed inferior or less certain than studies of present processes. This view commonly finds expression in statements like: "No one was there so we can never know what really happened." This view is false. The historical sciences are no less scientific, or testable, than the "hard sciences" (13).

Research in the historical sciences proceeds by an almost continuous process of hypothesis creation and testing. Predictions are continually tested against each new observation or analysis. Obtaining data from a newly analyzed sample or newly described locality is no different methodologically from obtaining data from a new experimental trial. In both cases, the new observations can be tested against expectations based on previous experience and theoretical predictions. If the predictions deduced from a hypothesis are not supported by new observations then that hypothesis is modified or rejected. Scientific research proceeds by an almost continual process of hypothesis creation and testing. Many past theories in the historical sciences have been discarded with the accumulation of new observations and the development of new theories of greater explanatory power.

Like all scientific disciplines, the historical sciences proceed by testing the predictions or expectations of existing models and theories. In geology, for example, the measurement and description of each new rock outcrop or subsurface core is a test of working hypotheses based on present understanding. If a specific rock unit is interpreted to be part of a meandering river system, then specific predictions can be made concerning the geometry of this rock body and the characteristics and distribution of associated sedimentary rocks. In modern meandering river systems a whole complex of sedimentary environments are present: channel and point bar deposits, levees, crevasse splays, overbank flood deposits, abandoned channels, freshwater lakes, etc. Each of these environments has its characteristic spatial relationships, sediment types, depositional features, and associated biota. If the original hypothesis of a meandering river system was correct, then further exploration and sampling of the area should reveal the predicted geologic features and their predicted spatial and temporal relationships. If the new observations are contrary to these predictions, then the hypothesis must be modified, or if necessary, abandoned.

All "theories" have a right to a hearing in the public science classroom. Because historical theories are viewed as untestable guesses, it is often argued that all "theories" have a right to a hearing in the public classroom. It is this fundamental public misunderstanding about the nature and centrality of theory in science, combined with the identification of evolution as a fruit of atheism or materialism, that provides the basis for the public call for the democratization of science. These misconceptions also underpin the public support for traditional creationism and intelligent design.

In the public mind, "fairness" demands that all voices have a right to be heard. However, few people have the skills to evaluate the validity of scientific claims. This includes those elected to local and state school boards. In the absence of critical thinking skills, marginal ideas, pseudoscience, and folk science may be favored because their conclusions agree with individuals' worldviews. In this way ideas, however unsupported, get equal access to the public – bypassing the rigors of research and peer review.

Furthermore, many people have been led to believe that creationist or ID arguments have been excluded from the science curriculum for political or social reasons, rather than for their failure to explain or predict observations. As a result, determining the content of public science curricula is seen as a political, not a scientific, issue. Public opinion polls are viewed as a valid basis for determining the content of public science curricula. It becomes the public's responsibility, not that of the community of trained scientists, to decide what qualifies as valid science.

However, good science is not determined by popular vote. Rather, it is the consensus of the community of science professionals that determines the currently best theories. That community includes individuals with a wide range of cultural and religious worldviews. The scientific enterprise is a human activity and thus imperfect. But it is the very diversity of the scientific community, and the incredible range of experience and knowledge of the natural world held by that community, that provides the best means of determining error and identifying the most practically useful and fruitful ideas. We do a great disservice to our children if we deny them the consensus understanding of that community.

Addressing public misconceptions as science educators:

As science educators, what do we do? From the discussion above, it is clear that scientific evidence and argument alone are not enough. The evidence will not persuade people if they hold fundamentally erroneous understandings of the scientific process. For many, the essence of science is not the process of inquiry and theory construction, but rather a body of accepted "facts" to be accepted on authority. When science is further seen as resting on a philosophy of materialism or atheism, there is a powerful barrier to science education and public science literacy.

The nature of science (NOS) must be an important component of teaching science, and evolutionary theory in particular. The NOS is communicated implicitly to students in all science courses. However, the impression given through science instruction commonly reinforces popular misconceptions rather than countering them. Portrayals of the history of science in science textbooks are notoriously simplistic and commonly present science as a steady march of enlightenment culminating in our current understanding. There is little sense of the human dimension of the scientific enterprise and its cultural, political and philosophical context. This can often reinforce the perception of science as the accumulation of encyclopedic knowledge. Laboratory and classroom activities are often structured to focus on obtaining the correct results, rather than on the process of inquiry itself. Similarly, assessment is commonly focused on knowing science content rather than understanding science as a way of knowing. Such an emphasis leaves students without the tools to critically evaluate competing scientific claims, or to understand the incomplete and open-ended nature of scientific conclusions.

The NOS is rarely taught explicitly beyond a simplistic recitation of "the scientific method." The understanding of the scientific method is often focused on a generic description of experimental method that really does not reflect science as it is actually done, especially in the historical sciences such as biological evolution. As found by Dagher and Boujaoude, such generic understandings do "not appreciate the distinctive nature of evidence, explanations, and predictions employed in evolutionary theory." They therefore argue that teaching the nature of science must be embedded within the context of specific theories. The meaning of any abstract NOS without such context may become "vacuous," and actually lead to the rejection of valid scientific conclusions. (14)

The NOS must be taught explicitly, and teaching strategies and lesson plans must be developed with understanding the NOS as their primary goal. As emphasized by Cough and Olson, "Teachers must play an active role in posing questions at strategic points to explicitly draw students' attention to NOS ideas. Just as students rarely develop accurate science ideas from activities alone, accurate NOS ideas will not be learned simply by doing activities or reading/watching historical and contemporary accounts of science in action." (15)

Students do not acquire an understanding of science as a process and a way of knowing through traditional science instruction. Teaching about the nature of science must be explicit, reflective, and taught within an applied context (16). The focus of science instruction must be the nature of science; it will not be passively learned or absorbed merely through the learning of science "facts." Communicating the nature of science must include: teaching the historical context and development of scientific theories, inquiry-based instruction, and explicitly teaching the methodological foundations of science within the context of specific theories.

Discussing the historical context of the rise of new scientific theories and models can be an effective way of presenting the human side of the scientific enterprise. Science becomes inherently more interesting when is seen as a truly human activity. Students can also better appreciate that, despite personal ambitions, personality conflicts, and political agendas, ideas that successfully resolve scientific questions and lead to further discovery rise to scientific consensus (even if that process is a long one). There are now many excellent historical treatments of important episodes and personalities in science that are accessible and historically accurate (17). Such accounts are particularly valuable in countering the popular "conflict" view of science and faith.

Having students become participants in scientific inquiry is an effective way to develop an understanding of the scientific process. In inquiry-based instruction, student problem solving focuses not on the solution but on the process of inquiry. This moves attention away from getting the right answer, to reflecting on the processes involved in trying to answer the question. Such inquiry-based instruction needs to be accompanied by explicit teaching on the nature of science. As discussed above, that teaching needs to be done within the context of a particular theory or hypothesis. Students need to know not only what the current scientific consensus is, but how that consensus was reached.

It can be legitimately argued that the structure and demands of current science curricula pose significant obstacles to implementing the suggestions above. Where can teachers find space in their teaching for this emphasis on the nature of science? While the pedagogical challenge should not be minimized, much of the teaching about the NOS can be embedded within the existing course content. Students already acquire a certain perception of what science is, accurate or not, during the course of their science education. The question then is not so much should we teach the nature of science, as how do we present science in such a way that the nature of science is accurately communicated.

CONCLUSIONS

Numerous fundamental misunderstandings about the nature, limitations, and practice of science underlie the public resistance to the conclusions of modern science. This is particularly true of evolutionary science, which has been falsely portrayed as an expression of an atheistic or materialist philosophy. Both traditional creationists and Intelligent Design supporters build their cases upon these false views of the scientific enterprise. Therefore, public challenges to the conclusions of science must be addressed not only by appeals to the evidence, but also by directly countering the widely-held erroneous views about the nature of science itself.

Public science education needs to be part of the solution rather than part of the problem. As science educators we must be attentive to teach not just the content of our science, but its methodological foundation. The nature of science must be taught consciously and explicitly. The nature of science needs to be taught as part of the subject content, and currently accepted theories need to be understood as the result of a long process of rigorous testing and challenge within a diverse community of scientists. Students need to understand science as a dynamic, exciting, open-ended, and thoroughly human activity. Science is a process of developing explanations for how our natural world works, of making sense of our diverse observations of the world around us. It is a limited way of knowing about our physical reality; it complements rather than conflicts with other human endeavors that seek to answer other more profound questions. Rather than being perceived as a threat, the scientific enterprise should be seen as a vocation open to anyone with a curiosity about the workings of the natural world.

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REFERENCES

1. Trani R: I won't teach evolution; it's against my religion. And now for the rest of the story.... Am Biol Teacher 66(6): 419-427, 2004.
2. Miller KB: The similarity of theory testing in the historical and "hard" sciences. Perspect Sci Christian Faith 54:119-122, 2002.
3. American Association for the Advancement of Science: "Science for all Americans." New York: Oxford University, 1990.
4. National Research Council:"National Science Education Standards." Washington, D.C.: National Academy Press, 1996.
5. Bishop B and Anderson C: Student conception of natural selection and its role in evolution. J Res Sci Teaching 27(5): 415-427, 1990. Rutledge M and Warden M: Evolutionary theory, the nature of science & high school biology teachers: Critical relationships. Am Biol Teacher 62(1):123-131, 2000. Dagher ZR and Boujaoude S: Students' perceptions of the nature of evolutionary theory. Sci Edu 89: 378-391, 2005.

6. Abd-El-Khalick F and Lederman NG: The influence of history of science courses on students' views of nature of science. J Res Sci Teaching 37: 1057-1095, 2000. Akerson VL, Abd-El-Khalick F and Lederman NG: Influence of reflective explicit activity-based approach on elementary teachers' conception of nature of science. J Res Sci Teaching 37: 295-317, 2000. Smith MU and Scharmann LC: Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. Sci Edu 83: 493-509, 1999.
7. Johnson P: Missionary Man. Church & State Magazine: April, 1999.
8. Moore JR: "The Post-Darwinian Controversies." Cambridge: Cambridge University Press, 502p., 1979.
9. Livingstone DN: "Darwin's Forgotten Defenders." Grand Rapids: Wm. B. Eerdmans Publishing Co., 210p., 1987. Livingstone DN, Hart DG, and Noll MA (eds.): "Evangelicals and Science in Historical Perspective." New York: Oxford University Press, 351p., 1999.
10. Miller KB (ed.): "Perspectives on an Evolving Creation." Grand Rapids: Wm. B. Eerdmans Publishing Co., 528p., 2003. Falk DR: "Coming to Peace with Science." Downers Grove: InterVarsity Press, 235p., 2004. Murphy GL: "The Cosmos in the Light of the Cross." Harrisburg, PA: Trinity Press International, 213p., 2003. Haught JF: "God after Darwin: A Theology of Creation." Boulder, CO: Westview Press, 221p., 2000. Polkinghorne J: "One World: The Interaction of Science and Theology." Princeton; Princeton University Press, 114p., 1986. Edwards D: "The God of Evolution." New York: Paulist Press, 144p., 1999.
11. Johnson PE: Response to Denis O. Lamoureux. In Darwin Defeated? (Johnson and Lamoureux, Eds) Vancouver, B.C.: Regent College Publishing, p.50, 1999.
12. Dembski WA: Introduction: Mere Creation. In Mere Creation: Science, Faith & Intelligent Design (Dembski, Ed.) Downers Grove: InterVarsity Press, p.20, 1998.
13. Miller KB: The similarity of theory testing in the historical and "hard" sciences. Perspect Sci Christian Faith 54:119-122, 2002.
14. Dagher ZR and Boujaoude S: Students' perceptions of the nature of evolutionary theory. Sci Edu 89: 378-391, 2005.
15. Clough MP and Olson JK: The nature of science: Always part of the science story. Sci Teacher (November): 28-31, 2004.
16. Scharmann LC, Smith MU, James MC and Jensen M: Explicit reflective nature of science instruction: Evolution, intelligent design & Umbrellaology. J Sci Teacher Edu 16: 27-41, 2005.

17. Rudwick MJS: "The Meaning of Fossils: Episodes in the History of Paleontology." Chicago: University of Chicago Press, 287p., 1985. Larson EJ: "Evolution's Workshop: God and Science on the Galapagos Islands." New York: Basic Books, 320p., 2001. Zimmer C: "At the Water's Edge." New York: Simon & Schuster, 290p., 1998. Weiner J: "The Beak of the Finch." Vintage Press, 1994. Tattersall I: "The Fossil Trail: How we Know What We Think We Know about Human Evolution." New York: Oxford University Press, 276p., 1995.