Commentary: On Teaching the Nature of Science and the Science-Religion Interface

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Science instructors, even at the college level, are routinely confronted with two facts about their students. First, most of our students have a poor understanding of the nature of science (NOS). Second, many of our students have religious objections to particular scientific theories that seem to cripple their ability to learn about, or even rationally discuss, these subjects (Antolin and Herbers, 2001). These problems tend to reinforce one another, in fact. Many scientists and science educators have complained, for example, that if people only understood the NOS, they would not oppose evolutionary theory so militantly (Antolin and Herbers, 2001; Farber, 2003; Miller, 2005; Rudolph and Stewart, 1998; Sprackland, 2005). But if students enter the classroom expecting their religious beliefs to be attacked, they may not even be listening if we try to explain the NOS (Smith, 1994). These mutually reinforcing problems obviously need to be addressed together, but it is very common for one or both of them to be ignored. Time after time, national scientific organizations have urgently called for students to be taught the NOS (AAAS, 1989; NAS, 1998; NRC, 1996; NRC, 1997; NSF, 1996), but whatever is happening in the classroom, students are usually coming out with very naïve conceptions (Abd-El-Khalick and Lederman, 2000; Moss et al., 2001). Scientists typically do not think that religion is an appropriate subject for discussion in science classes (Ecklund, 2007), but as Farber (2003) points out, "Religion resides under the surface in any discussion of evolution." We add that religion resides under the surface in any discussion of the NOS, because a discussion of what science is must also address what it *isn't.*

The problem goes beyond a simple case of neglect, however. Here we argue that there are several reasons why students are still graduating in droves with inadequate views of the NOS and strong anti-evolutionary sentiments. 1) Science educators often neglect teaching the NOS because they feel pressure to cover a certain amount of science "content," and it takes too much time to adequately teach the NOS. 2) But even if they do address the NOS, scientists and science educators often harbor naive views of the NOS similar to their students' views. 3) Furthermore, even those who do have more sophisticated views of the NOS typically soft-pedal those aspects of the NOS that might lead their students to adopt more sophisticated views. 4) Science educators usually neglect to discuss students' religious objections to scientific theories because they are typically not very religious themselves, but 5) if they do, they often make the situation worse by making outrageous gaffes regarding the science-religion interface. 6) Finally, standard resources meant to help science teachers teach the NOS and deal with religious objections actually encourage instructors to soft-pedal certain aspects of the NOS and make naive claims about the science-religion interface.

In the following sections, we further explain and support the above characterization of this complex problem, and then describe a suggested course of action.

A COMPLEX PROBLEM

No Time for the NOS

The observation that science education generally neglects the NOS in favor of "content" is so common (Abd-El-Khalick et al., 1998; Abd-El-Khalick and Lederman, 2000; Abd-l El-Khalick et al., 2008; Bauer et al., 2000; Bell et al., 2000; Bencze et al., 2006; Hipkins and Barker, 2005; Lederman, 1992; Rudolph and Stewart, 1998; Southerland et al., 2003) that Pitt (1990) could call the idea that science education even exists in this country a "myth." (How can you teach "science" without addressing what "science" is?) And it is common for science educators to complain that teaching the NOS takes valuable time away from teaching science content knowledge (Irwin, 2000; Leach et al., 2003; Reif, 1995), which is typically the focus of standardized tests. This dilemma is not restricted to science education, but is part of a larger struggle about educational reform. While it is very typical for subjects to be taught in simple fact-memorization mode, reformers have been encouraging teachers to design their courses to require higher order thinking skills, and even to help students think about the subject more like experts (Fink, 2003; NRC, 2000). Any scientist would likely agree that scientific thinking is a valuable skill in any number of non-scientific pursuits—more valuable than memorized "facts." Therefore, we suggest that the only thing stopping many of them from incorporating the NOS into their classes is a failure to grapple with the problem of what their courses really should be accomplishing.

NAïVE REALISM -"GOOD SCIENCE" VS. "JUNK SCIENCE"

Many science educators do make some attempt to teach the NOS, but their view of the NOS is at least 50 years out of date. That is, their views of the NOS are generally consistent with the "Logical Empiricist" or "Logical Positivist" school of thought that dominated the philosophy of science in the first half of the twentieth century (Knain, 2001; Rudolph and Stewart, 1998; Yerrick et al., 1998). Although there were many differences among Logical Empiricist philosophers, this school of thought is best known for the *verification criterion,* which says that statements are only meaningful if there is some way to

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verify whether they are true or false (Rosenberg, 2000). Science, especially, was thought to be a system in which only verifiable statements should be allowed. This provides a simple way to talk about the NOS—observations are made, hypotheses are formulated, and more observation either verifies the hypothesis, or it doesn't. A thoroughly "verified" hypothesis is then considered to correspond fairly exactly to reality.

Logical Empiricism was long ago thoroughly discredited by a number of critics, notably the philosopher Karl Popper. Popper showed that verifiability was too strong a criterion for science—there is really no way to ultimately "verify" scientific statements. Rather, Popper argued that statements, if they are to be considered scientific, should be "falsifiable." In other words, even though scientific claims must remain "forever tentative," because they can never be totally verified, they may be discredited by a single, definitive experiment (Popper, 1934). Many scientists and science educators adopt something close to Popper's view, and in fact, "falsifiability" has been extensively used in the media and courts as a criterion to distinguish endeavors like "Creation Science" from true science (Laudan, 1982; Ruse, 1986,2003).

Clearly, Logical Empiricism is both idealized and naïve, but it becomes even more so in the hands of students and scientists who aren't particularly self-reflective. Thus, we sometimes see scientists making absurd statements about the NOS; e.g., zoologist Robert Sprackland wrote that "Scientists make only one universal assumption in their work: Reality is real" (Sprackland, 2005). This kind of thinking takes Realism—the idea that science aims to describe the ultimate reality of things—to the extreme, grossly overestimating the degree to which the human mind has certain access to ultimate reality, and oversimplifying the scientific process. Hereafter we will refer to this kind of thinking as "naïve Realism," to distinguish it from more sophisticated Realist philosophies. Even Popper's version of Realism has been called into question by subsequent work, however, because scientific theories depend on such a complex web of auxiliary assumptions that "No single falsifying test will tell us whether the fault lies with the hypothesis under test or with the auxiliary assumptions we need to uncover the falsifying evidence" (Rosenberg, 2000). (Falsifiability is still a useful concept, however, since scientists value hypotheses that make more daring predictions.)

Still, the scientific organizations that are recommending reforms in teaching science typically focus on three basic aspects—the *empirical, tentative,* and *creative* natures of science (Kurdziel and Libarkin, 2002). A science educator whose views of the NOS are similar to Popper's would be able to accept all three of these, whereas a naïve realist would at the least have problems accepting the tentative NOS, and would certainly downplay the role of creativity. This is a key point. Philosophers of science disagree among themselves about the exact NOS (Alters, 1997; Farber, 2003; Hurd, 2002; Jenkins, 1996; Knain, 2001; Koertge, 2000; Matthews, 1998; Rudolph and Stewart, 1998; Smith and Scharmann, 1999; Stanley and Brickhouse, 1994; Turner and Sullenger, 1999; Yerrick et al., 1998), but there are some points that nearly everyone agrees are essential ingredients of scientific thinking (Matthews, 1998; Osborne et al., 2003; Smith and Scharmann, 1999), including the characterization of scientific theories as empirical, tentative, and creative. If students never learn about the creative and tentative NOS, they will not be able to make informed judgments about the value they should place on scientific claims. If they debate scientific claims, they will invariably employ straw man arguments. It might seem strange that naïve realists would argue against scientific claims, but anyone who watches

Box 1. In a recent *Discover* magazine article, Todd Pitock reported on a number of interviews with devout Muslim scientists who explained how they view the interface between science and their religion. Some of the scientists interviewed actively pursue scientific proofs of Islamic teachings, but others see science and religion as distinct activities. Pitock's report of his interview with Waheed Badawy, a chemistry professor at the University of Cairo who sees science and religion as "discrete pursuits," provides a glimpse of how misconceptions about the nature of science (NOS) can lead to wholesale rejection of unpopular theories.

> "Islam has no problems with science," he says. "As long as what you do does not harm people, it is permitted. You can study what you want, you can say what you want." What about, say, evolutionary biology or Darwinism? I ask. (Evolution is taught in Egyptian schools, although it is banned in Saudi Arabia and Sudan.) "If you are asking if Adam came from a monkey, no," Badawy responds. "Man did not come from a monkey. If I am religious, if I agree with Islam, then I have to respect all of the ideas of Islam. And one of these ideas is the creation of the human from Adam and Eve. If I am a scientist, I have to believe that." But from the point of view of a scientist, is it not just a story? I ask. He tells me that if I were writing an article saying that Adam and Eve is a big lie, it will not be accepted until I can prove it. "Nobody can just write what he thinks without proof. But we have real proof that the story of Adam as the first man is true." "What proof?" He looks at me with disbelief: "It's written in the Koran." (Bauer et al., 2000; Pitock, 2007)

Notice how Badawy distinguished "science," with which "Islam has no problems," from evolutionary theory, which he rejected on the basis that it conflicts with the creation story in the Koran. Isn't evolutionary theory "science"? His answer seems to be that it will never be science until it has been *proven.* For anyone acquainted with the last several decades of research on the history, philosophy, and sociology of science, it is obvious that this is an absurd standard by which to judge whether a theory can be considered "scientific." However, Badawy was able to complete years of university training in science, work as a professional scientist in Germany, and teach university science courses for decaides—all the while maintaining this naïve, but extremely common view of the NOS. This example clearly illustrates three important points that we argue here.

- Science educators have been extraordinarily unsuccessful at giving students a realistic view of the NOS.
- Typical naive views of the NOS can facilitate straw-man arguments that allow people to unfairly dismiss unpopular scientific theories without giving them a proper hearing.
- Quixotic attempts to avoid the appearance of conflict between science and religion only exacerbate this problem.

television news reports quickly gets the idea that sometimes different scientists come to opposite conclusions—in fact common journalistic practices may lead people to overestimate the degree of controversy in the scientific community (Boykoff and Boykoff, 2007). A naive realist will typically separate those claims into two categories: "good science" (i.e., "just the facts) and "junk science" (i.e., anything that goes beyond the facts in any significant way.) For example, the literature promoting "Creation Science" and "Intelligent Design Theory" tends to highlight gaps in, and areas where experts disagree about, evolutionary theory. So what? All scientific theories have gaps and grey areas. But naïve realists who don't want to accept evolutionary theory will take any hint of tentativeness or creativity as license to reject it. E.g., we cannot go back in time to really test evolutionary theory, so it must be "junk science." (See Box 1 for a particularly striking example of this phenomenon.) Even when science educators recognize that naïve realist views of the NOS must be challenged in the classroom, many of them hesitate. Are students in lower-division college and secondary school classes even capable of this kind of thinking? And even if certain groups have problems with individual scientific theories, the public accords science quite a bit of authority. If we start trumpeting the creative and tentative nature of science, will we be giving people the rope they need to hang us?

THE NATURE OF SCIENCE AND THE "SCIENCE WARS"

This fear is not entirely unfounded, as the "Science Wars" of the last decades (especially the 1990's) have demonstrated (Parsons, 2003). Since the publication of Thomas Kuhn's *The Structure of Scientific Revolutions* (Kuhn, 1962), a vast amount of historical data and a number of strong philosophical arguments have been marshaled to show that science is not an entirely rational activity. (This is not to say it is *irrational*, but that it has significant *extra-rational* components.) It turns out that scientists have not, do not, and probably cannot, come up with scientific explanations or decide between competing explanations on the basis of a strict, rational set of rules. In fact, strong historical and philosophical arguments can be made to show that scientific theories are *always* "underdetermined" by the data (Hacking, 1999; Laudan, 1981; Pickering, 1984; Rosenberg, 2000). Scientists have generally been willing to at least give lip service to these ideas, and hence, resources for teaching the nature of science, such as *Teaching Evolution and the Nature of Science* published by the National Academy of Sciences (NAS, 1998), do mention empirical, tentative, and creative aspects of the discipline. These points naturally bring up the question of how closely scientific theories describe ultimate reality. If scientific theories are always underdetermined by evidence, and theory choice is not a completely rational process, then it is possible that scientific theories are merely mental constructions that help us organize our experiences, but have little to do with the ultimate reality of things (Okasha, 2002). This is not necessarily to say that theories are useless—we can still predict quite a number of useful things by means of these organizational schemes (Kelly, 1997). It was inevitable that some academics would take such conclusions to extremes, and so critics (usually labeled post-modernists, constructivists, or anti-realists) push a view of science as *inherently* "mechanistic, materialist, reductionist, empirical, rational, decontextualized, mathematically idealized, communal, ideological, masculine, elitist, competitive, exploitive, impersonal, and violent" (Aikenhead, 1997). Others have pushed extreme forms of intellectual relativism that, frankly, seem out of place in academia (Parsons,2003). There is no denying that some people are "out to get" science, but some scientists (even ones who are not naïve realists) have overreacted to this challenge. The fact is that it is impossible for us to tell when we have succeeded in describing ultimate reality. But some scientists claim that science gets at the truly real as dogmatically as religious zealots affirm their own beliefs. For example, Nobel laureate Steven Weinberg announced that "If we ever discover intelligent creatures on some distant planet and translate their scientific works, we will find that we and they have found the same laws" (Weinberg, 1996). The prominent British biologist Lewis Wolpert (2002) criticized a rather moderate description of the NOS by a philosopher of science (Kitcher, 2001) because Wolpert could not stomach the principle of underdetermination. "I would have liked," Wolpert said, "examples of theories equally able to explain, for example, the coding of proteins by DNA or Harvey's account of the circulation of the blood." But Kitcher did provide some excellent examples of empirically successful theories that were later dropped in the face of new evidence. Is it really such a stretch to suppose that some of our more recent theories could one day be toppled or severely modified in a similar way? Do we have to wait for someone to come up with viable alternative theories in every case before we can admit the mere possibility of alternatives? Wolpert concluded his review by asking, "And I am left wondering, do philosophers really have anything useful to tell scientists?" We think so. Even if we cannot definitively rule out the idea that theories are merely useful mental constructions, simple but powerful arguments have been made in favor of a "modest realism." According to Matthews (1998), both modest realists and constructivists can agree that

> ... science is a human creation, that it is bound by historical circumstances, that it changes over time, that its theories are underdetermined by empirical evidence, that its knowledge claims are not absolute, that its methods and methodology change over time, that it necessarily deals in abstractions and idealizations, that it involves certain metaphysical positions, that its research agendas are affected by social interests and ideology, that its learning requires that children be attentive and intellectually engaged, and so on. (Matthews, 1998)

However, admitting all those points does not mean that we have to abandon the idea that scientific theories really do have some powerful connection to reality. Kitcher (2001) illustrated this point by comparing scientific theories to maps. It seems obvious that more modern maps of the world are generally "better" than older ones; i.e., the newer maps include whole continents that were omitted from the earlier, we can use the newer maps to achieve greater precision in navigation, etc. But no reasonable person would be so deluded as to think even a modern map is the reality it intends to portray, or **is** even an exact scale model. We can point to huge numbers of oversimplifications and errors in any map, if we look closely enough. Different maps of the same area may be created for entirely different purposes, and therefore emphasize or ignore/gloss different things. But what would it take to make a map that allows us to navigate the world so successfully, but is merely a mental construction with no concrete link to reality? How could our modern maps be so much more useful for navigation, but not be any closer to representing reality than the older ones? Normal human experience is that our ideas do not work well consistently unless they are at least substantially right. Therefore, it seems reasonable to suppose that many of our more empirically successful scientific theories are at least on the right track in some ways. This is a persuasive argument, and one that most people are capable of understanding, ***so*** it seems possible that we can present scientific thought in a way that is both honest and compelling. People respect honesty—and people respect results. If scientists want the public to respect science and give it a hearing, then we need to portray the NOS in a way that is recognized as brutally honest and humble. After we have done this, many (not all) people who would normally dismiss science will give it a hearing. And when they do, scientists can present a stunning array of successes to show that it is a reasonable and effective way to go about finding out how the world works.

THE "SCIENCE WARS" AND SCIENCE EDUCATION

As we mentioned above, when the Science Wars hit the science classroom we are generally not battling the academic left. Rather, we are often faced with a number of students who hold conservative religious views that sometimes conflict with scientific orthodoxy (Abd-El-Khalick and Lederman, 2000; Moss et al., 2001). These students do not usually spout constructivist or relativist rhetoric; instead, they tend to be naive realists who will reject scientific theories if they are shown to incorporate any sort of tentativeness or creativity. Therefore, even if science educators are inclined toward a more modest realism, we can sometimes find it tempting to gloss over these aspects of the NOS so as not to give these students an excuse to dismiss science as a whole. One geologist, Steven Dutch of the University of Wisconsin-Green Bay, put the problem in these terms.

> Students at this stage of development want certitude. If they do not get it from science, they will not respect science for its honesty but rather will conclude that science has no authority. They will seek certitude from someone who does claim to have it, and there is no shortage of charlatans who claim to have it. As taxpayers, they will justifiably ask why they should pay for activities that do not lead to certainty. And to be blunt, science *does* find truth.... (Dutch, 1996)

Most science educators would never make this admission in print, but we do not believe that Dutch is some kind of extremist. Rather, in his writings he exhibits a kind of split personality that is common among scientists who have to deal with some students who think in ways that are foreign to the instructor. In a later publication, for example, Dutch advocated teaching more realistic accounts of the NOS to help religious students deal with science-religion conflicts.

> Ideally, we would like to move the students to the point where they can reconcile the findings of science with their beliefs with as much integrity to both as possible. If reconciliation is not possible, we would like students to understand why science reasons and evaluates evidence as it does, and to see that the methods of science are neither arbitrary nor deliberately intended to deny or undermine religious belief. (Dutch, 2002)

But he hung on to the notion that we cannot be frank about the tentative NOS when addressing religious fundamentalists. "Asserting the tentativeness of science to dogmatic believers is likely to be counter-productive because they commonly view the tentativeness of science as weakness rather than strength" (Dutch, 2002).

Once again, even if we disagree with this approach, we have to admit that there is some risk involved in exposing students to more sophisticated renditions of the NOS. For example, a proponent of Intelligent Design (ID) theory like John Angus Campbell (2003) could favorably review critiques of the naïve philosophy that informs most science education, and then argue that inclusion of ID theory in public school science curricula would help address this deficiency. What better way to bring out the assumptions upon which orthodox science is based, than by introducing an alternative version of science that is not based on all the same assumptions? Most science educators would balk at such a solution, however, because they view the ID movement as having very limited support among credentialed scientists, and do not think it deserves the airtime.

WAFFLING AND THE PROBLEM OF CONCEPTUAL CHANGE

So what should we do—teach the NOS as merely empirical, or risk a backlash when we address its tentative and creative aspects? Unfortunately, there is also a tempting, but mostly useless, middle road. That is, we can *mention* the tentative and creative aspects of the NOS and then immediately start downplaying their significance. For example, the National Academy of Sciences' book, *Teaching About Evolution and the Nature of Science* (NAS, 1998), says that "the statements of science should never be accepted as 'final truth.'" But then it goes on to say,

> Instead, over time they generally form a sequence of increasingly more accurate statements. Nevertheless, in the case of heliocentricism as in evolution, the data are so convincing that the accuracy of the theory is no longer questioned in science.

Immediately thereafter, it mentions the creative NOS in an extremely weak fashion.

> Third, scientific progress depends on individuals, but the contributions of one individual could be made by others. If Copernicus had kept his ideas to himself, the discovery of

> heliocentricism would have been postponed, but it would not have been blocked, since other astronomers eventually would have come to the same conclusion.

Would such language do anything to move students away from typical naïve realist misconceptions? We doubt it. In support of our point of view, we can appeal to the major points of conceptual change theory (CCT). CCT has sometimes been identified with a broadly constructivist agenda, but in fact it can be consistent with a number of non-constructivist philosophical positions (Kelly, 1997). CCT begins with the recognition, gleaned from cognitive studies, that misconceptions cannot be easily replaced in a student's mind. Three basic steps need to be taken (Kelly, 1997; Posner et al., 1982; Watson and Kopnicek, 1990). First, the misconception must be confronted directly, preferably through experimentation, but possibly also through "refutational text" (Guzzetti et al., 1997). Second, the alternate conception must be given *in exceptionally plain language.* Third, the student must be allowed to experiment with the new conception.

If we want students to come away with a more sophisticated view of the NOS, we need to confront naive realism and, articulate an alternative in much more direct language than we sometimes have in the past. The question, however, is whether we really want this kind of result.

WHEN SCIENCE MEETS RELIGION

Abd-El-Khalik and Akerson (2004) showed that one of the major barriers to student progress in understanding the NOS is the view that science and religion are competitors. They found that students' resistance to learning was lessened when they were able to see science and religion as distinct, rather than competing, enterprises. In fact, it is very common for scientists and science educators to try to address this problem. It is our opinion, however, that the strategies typically employed can do more harm than good, because 1) scientists often have a very poor understanding of religious thought— especially the more conservative varieties—and 2) when they try to articulate the difference between science and religion, their characterizations of the science religion interface can come off sounding very patronizing to conservative religious people.

Whereas around 90% of the general population in the United States reports that they believe in God, only about 35-40% of scientists are believers (Ecklund and Sheitle, 2007; Larson and Witham, 1997, 1998). And religious scientists are typically much more liberal in their beliefs than the general population. For example, while about 13.6% of the population identifies itself as "evangelical" or "fundamentalist," only 1.5% of scientists at elite universities did so in a recent survey. While the percentage of the general population that identifies itself as liberal, moderate, or conservative Roman Catholic was 7.0%, 7.4%, and 6.9%, respectively, the corresponding figures for the scientists were 6.2%, 1.7%, and 0.7%. When Jewish scientists at these institutions ranked their beliefs compared to the general population on a 7-point scale, 1 being the most liberal and 7 being the most conservative, the average response was 2.19 (Ecklund and Sheitle, 2007). Why are scientists so much less inclined toward traditional religious forms? Ecklund and Sheitle (2007) found that the major predictor of religiosity in scientists was the home environment in which they were raised. That is, scientists generally do not lose their faith as university students, but rather people from non-religious or religiously liberal backgrounds disproportionately self-select into scientific disciplines.

While it is common for scientists to lament the scientific illiteracy of the general population, Ecklund and Sheitle (2007) point out that scientists are generally religiously illiterate when it comes to traditional forms. Since scientists are not as religious as the general population, and are much less likely to have even been raised in a religious home, traditional forms of religious thought are often utterly foreign to them. Ecklund (2007) notes that the scientists surveyed generally do not consider religion to be a proper topic of conversation in their professional setting, but students are bringing issues related to religion into the science classroom whether their professors like it or not. In response, science professors often refuse to discuss the topic, but many who are otherwise disinterested in religion are now looking for ways to insightfully discuss the interface between science and religion with their students.

Many scientists who are novices in the realm of conservative religious thought are, unfortunately, the ones who are coming forward to provide resources to facilitate such discussions. One example is *Teaching About Evolution and the Nature of Science* (NAS, 1998; Smith, 1994). The authors of this book answered the question, "Can a person believe in God and still accept evolution?" by making the claim that "Most religions of the world do not have any direct conflict with the idea of evolution." This is a reasonable point. But then they went on to give their view of why some religions are not so accepting.

> At the root of the apparent conflict between some religions and evolution is a misunderstanding of the critical difference between religious and scientific ways of knowing. Religions and science answer different questions about the world. Whether there is a purpose to the universe or a purpose for human existence are not questions for science.

If we deconstruct this passage, we find three claims implied. First, there are no *real* science-religion conflicts — only "apparent" conflicts. Second, these apparent conflicts arise because people from certain religions *do not understand* what kinds of questions their religion can answer. Third, religious thought can *only* answer questions about ultimate meaning, ethics, and so forth, whereas scientific thought can only address questions about material causes (cf. Gould, 1999), therefore the two can never come into real conflict. A more recent publication of the National Academy of Sciences and the Institute of Medicine, *Science, Evolution, and Creationism* (NAS and IM, 2008), at least admits that "Scientific advances have called some religious beliefs into question." But it goes on to once again pronounce that we should not confuse "the roles of science and religion by attributing explanations to one that belong in the domain of the other."

Consider how a Christian fundamentalist might perceive these claims. For such a person, the Bible makes any number of claims about the order and timing of the creation of the Earth, the time and place of various events, including supernatural events, and the actions of real, historical figures. And furthermore, for such a person the Bible was written through direct, divine inspiration. Who do the scientists who authored *Teaching Evolution and the Nature of Science* think they are, that they can disallow God from answering certain types of questions? And who do they think they are to tell conservative religious people that they *misunderstand* the claims of their own religions? Wouldn't people who are immersed in this kind of religious thought be in a better position to decide whether the claims of their religion conflict with various scientific claims? Or are the authors really implying that such people ought to convert to religious traditions that are generally more accepting of science? Scientists who make pronouncements like these not only come off sounding naïve and patronizing, but also like missionaries for a particular type of religious thought (cf. Goodenough, 1999; Provine, 2003).

Such attempts to artificially disengage scientific and religious thought can go even further. The authors of *teaching About Evolution and the Nature of Science,* for instance, addressed the question, "Aren't scientific beliefs based on faith as well?"

> Usually "faith" refers to beliefs that are accepted without empirical evidence. Science differs from religion because it is the nature of science to test and retest explanations against the natural world. Thus, scientific explanations are likely to be built on and modified with new information and new ways of looking at old information. This is quite different from most religious beliefs.
>
> Therefore, "belief" is not really an appropriate term to use in science, because testing Is such an important part of this way of knowing. If there is a component of faith to science, it is the assumption that the universe operates according to regularities — for example, that the speed of light will not change tomorrow. Even the assumption of that regularity is often tested—and thus far has held up well. This "faith" is very different from religious faith. (NAS, 1998)

One of the authors of *Teaching About Evolution,* Eugenie Scott, explained in another publication what was meant by the claim that faith "refers to beliefs that are accepted without empirical evidence."

> Sometimes people believe a statement because they are told it comes from a source that is unquestionable: from God, or the gods, or from some other supernatural power.... A problem with revealed truth, however, is that one must accept the worldview of the speaker in order to accept the statement; there is no outside referent. (Scott, 2004)

In this version of religious thought, people believe certain doctrines just because someone, somewhere, put "God" in the byline. There is no empirical evidence for religious beliefs because they are connected only to inner experiences or unsubstantiated appeals to authority, and have no "outside referent."

At best, this is an extreme oversimplification. The claims of the dominant Western religious traditions (Judaism, Christianity, Islam) are often linked to historical places, cultures, people, and events. For example, the Bible claims that an earthquake destroyed the walls of Jericho around 1400 B.C. after God commanded the armies of Israel to march around the city blowing trumpets, and then the city was burned. Archaeologists have confirmed that the walls of Jericho did fall, and the city was burned, around 1550-1400 B.C. (Netzer, 1990). But even if archaeological investigations of Jericho have confirmed some aspects of the Bible story about the conquest of Jericho, it does not prove that God, or even Joshua and the armies of Israel, had anything to do with the city's destruction. Archaeologists generally hold that the Israelites did not settle Palestine until sometime in the 13th century B.C., contrary to the biblical account. Certainly "Biblical Archaeology" has not given unambiguous support to the historicity of the biblical narrative, and archaeologist William Dever (2006) writes, "The clock cannot be turned back to the time when archaeology allegedly 'proved the Bible.' Archaeology as it is practiced today must be able to challenge, as well as confirm, the Bible stories." But if so, it is absurd to make a blanket statement that religious beliefs are not connected to "outside referents," and therefore completely immune to testing.

Some might object that it is precisely the supernatural elements of an explanation such as the Biblical story of Jericho that cannot be tested, but such objections carry little weight. We are not aware of any scientific theories whose predictions are *all* testable; we can only test predictions that happen to intersect with normal human experience. We cannot "see" atoms, for example, but rather can only surmise their existence and properties by various responses logged with spectrometers, scanning tunneling microscopes, and so forth. Paleontologists and biologists wish they could observe macroevolutionary processes, but they are stuck observing fossil structures and occurrence, microevolutionary processes, relationships between DNA from different organisms, and so on. Pick any theory, and we can find parts of it that go beyond our ability to observe. (Hence, the principle of "underdetermination.") But the more of a theory's predictions we can confirm, the more confident we are that it is on the right track.

It is fair to say, however, that religious claims are *less likely* than scientific theories to be empirically testable (Barbour, 1974), but this is a difference in degree, not kind. In both cases, the explanation (i.e., the theory or doctrine) goes beyond the empirical data via various presuppositions that provide a framework within which to interpret observations.

If religious beliefs were really so completely disconnected from the world of normal human experience (remember that "empirical" simply means "based on sensory experience,") we find it hard to believe that most people would bother with them. Instead, it seems more accurate to say that religions generally have different standards than science regarding what kinds of sensory experiences can count as evidence for beliefs.

This leads into another important point. It is quite common for science educators to unfairly characterize science as an impregnable bastion of objectivity and open-mindedness, and religion as a hodge-podge of immutable, dogmatic assertions. *Teaching Evolution and the Nature of Science* asserts, "Thus, scientific explanations are likely to be built on and modified with new information and new ways of looking at old information. This is quite different from most religious beliefs" (NAS, 1998). But even if there is some truth to this characterization, it confuses the dogmatism of particular believers with some kind of inherent immutability in religious doctrine (Laudan, 1982). The truth is that religious beliefs have often been modified in response to intellectual and social currents (Olson, 1999; Stead, 1994). Conversely, Lakatos (1970) and others (e.g., Feyerabend, 1993; Kuhn, 1962) have shown that a little dogmatism in scientists is often a good thing. If some observations seem to conflict with a theory, that is, it may be that the observations have been misinterpreted via any number of auxiliary assumptions and hypotheses, or that the theory is correct at its core, but mistaken in certain details. Therefore, sometimes a mark of a great scientist can be a dogmatic clinging to theory in spite of the evidence—searching for ways to reconcile the two. Where would we be if Copernicans like Galileo had abandoned the core concepts of their theory just because circular, heliocentric planetary orbits did not fit the observational data? And what scientist has not at least once uttered the cliche, "Old theories never die—their adherents do"? If we dismissed scientific theories as dogmatic assertions just because some scientists assert them dogmatically, what would we have left?

No matter how much we might wish that science and religion represent "non-overlapping magisteria" (Gould, 1999), it just isn't so (Goodenough, 1999). On the one hand, science "is limited to explaining the natural world through natural causes. Science... can say nothing about the supernatural" (NAS, 1998). This position is known as "Methodological Naturalism" (Pennock, 1996; Ruse, 2001, 2003). Religious systems of thought, on the other hand, usually do allow for supernatural causes, but both religion and science may attempt to explain parts of the observable world, as we have seen. Thus, science and religion can sometimes end up trying to explain the same things on the basis of vastly different rules about what counts as a valid explanation. So why is anyone surprised that conflicts sometimes arise between the two?

Perhaps the main reason such an obvious point is often glossed in discussions of the science-religion interface is fear of backlash. If scientists were to advertise the inevitability of occasional science-religion conflicts, some people (especially naïve realists) might take that as an admission that science is "anti-religion." The truth is that there are practical reasons for methodological naturalism that can be compelling even for scientists who hold conservative religious beliefs. But if the perception that science and religion are in competition is a major barrier to student learning about the NOS and science content (Abd-El-Khalick and Akerson, 2004), then are science educators compelled to offer oversimplified, patronizing accounts of the science-religion interface to sidestep this perception, even if they often backfire?

SOME SUGGESTIONS

The best policy, in our opinion, is to offer students the unvarnished truth, as far as possible. We should make it perfectly clear that when we say science is tentative and creative, we mean it. And if we are going to insist that scientific practice adhere to the principle of Methodological Naturalism, we should make it clear that this makes a few science-religion conflicts inevitable.

Will this diminish science in the eyes of our students? The risk is real, but we have some evidence that it is much less serious than one might think. In a companion piece to this commentary (Bickmore et al., this issue), we report on a program we developed for teaching the NOS called "Science as Storytelling," which forcefully acknowledges the tentative and creative aspects of science and the possibility of science religion conflict. Even though our students were essentially all conservatively religious, our experience was that when they grasped these points they were largely able to come to terms with the idea that the adoption of Methodological Naturalism in science inevitably results in some science-religion conflicts. And the vast majority of them accepted that science, nevertheless, probably should operate in this manner. Many of the students reported that the program helped them feel more irenic toward science and scientists, and freer to consider other points of view, since they didn't feel like their religious beliefs were being directly attacked.

At this point, some readers might object that of course neutering science by equating it with "storytelling" would make conservative religious students feel better about science. We ask these readers to reserve judgment until they have read our companion piece in this issue of the *Journal of Geoscience Education* (Bickmore et al., this issue). While the name was designed, for pedagogical reasons, to be shocking, the balance of the *Science as Storytelling* program is a rather straightforward Modest Realist explanation of the NOS coupled with some straight talk about the science-religion interface. It is designed to help students confront their Naïve Realist misconceptions, but then persuade them that science is still a reasonable way of trying to understand the world.

Some might wonder, for instance, how so many conservatively religious students came to think that Methodological Naturalism is a good idea, even though we explicitly told them that it causes science-religion conflict. The answer is that we gave them a number of practical reasons for its adoption and introduced them to the concept of "simplifying assumptions." That is, scientists and others frequently make assumptions they know are not true, or at least may not always be true, in order to make progress possible. We often assume planets and atoms are perfectly spherical when calculating forces of interaction because it makes the math easier, even though we know the assumption isn't exactly true. People go about their business as if they weren't slated to die in a horrible natural disaster that day because they consider the possibility unlikely. Similarly, it is completely rational for a scientist who believes in the existence of supernatural causes to adopt Methodological Naturalism when doing science because she believes that the world can mostly be explained via natural processes.

Whether or not our program succeeds at addressing the complex problem we have outlined here, we are convinced that something along these lines needs to be done. The alternative is to continue obfuscating these ssues by mixing the truth with waffling and sound bites. A scientific theory is tentative... but "increasingly more accurate" as time goes on, so that at some point "the accuracy of the theory is no longer questioned in science" (NAS, 1998)? The production of a scientific theory requires considerable creativity... but others "eventually would have come to the same conclusion" (NAS, 1998)? Science and religion do not conflict... as long as religion never addresses any topics that intersect with "outside referents" (Scott, 2004)? In contrast to scientific explanations, religious beliefs are not "likely to be built on nd modified with new information and new ways of looking at old information." And yet, "Most religions of the world do not have any direct conflict with the idea of evolution" (NAS, 1998)? Taken together, these rather commonplace claims make no sense.

If we refuse this challenge to promote clearer understanding of the NOS and the science-religion interface we certainly squander any clear-cut claim to the moral high ground in debates about whether alternative viewpoints like Intelligent Design Theory and Young Harth Creationism should be taught in the classroom. One of the major complaints of Intelligent Design proponents, for example, has always been that evolutionary theory necessarily conflicts with conservative religious viewpoints, since the assumption of Naturalism (methodological or not) precludes any intelligent, directing influence, but scientists and science educators bend over backwards to make it sound like there is no conflict (Johnson, 1993). Certainly this is a valid complaint, as we have shown, even if the situation is largely the result of naivete on the part of science educators.

We cannot afford this. Those who advocate teaching Creation Science or Intelligent Design Theory in public school science classes often package their case in the form of arguments about "fairness" which are red herrings, but still sound convincing to many Americans (Pennock, 2001). To the extent that we actually are treating religious viewpoints unfairly and obfuscating the NOS, these "fairness" arguments are given unnecessary weight.

So while there is some risk involved in teaching more sophisticated renditions of the NOS and the science-religion interface, we maintain that it is minimal compared to the risk involved in maintaining the status quo.

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