Science, Pseudoscience, and Nonsense

By Clyde Freeman Herreid

If we teach only the findings and products of science—no matter how useful and even inspiring they may be—without communicating its critical method, how can the average person possibly distinguish science from pseudoscience?
—Carl Sagan (1996, p. 21)

A favorite pastime of academicians is to bemoan the scientific literacy of the American public. When we listen to politicians who claim that climate change is a hoax, there is good reason to be concerned. So it is no surprise to learn that 93% of American adults and 78% of those with college degrees are scientifically illiterate (Hazen, 2002). Nowhere is this better demonstrated than in a poll disclosing that the United States is next to the bottom of the list of 34 nations in the public acceptance of evolution (Miller, Scott, & Okamoto, 2006). According to *Science and Engineering Indicators 2002* (National Science Foundation, National Center for Science and Engineering Statistics, 2002), 30% of the American public thinks that UFOs are alien spaceships, 40% believe that astrology is scientific, 60% believe in extrasensory perception (ESP), 70% accept magnetic therapy as credible, and 88% accept alternative medicine.

Education by itself doesn't offset the problem. Belief in ESP hardly decreased from 65% in high school graduates to 60% in college graduates, and belief in magnetic therapy dipped from 71% in high school graduates to 55% in college grads. As far as belief in alternative medicine went, the college graduates actually gave it higher approval (92%) than high school graduates (89%) did. But the most disheartening part of the survey was the fact that 70% of the American public doesn't understand the scientific process. *Science and Engineering Indicators 2014* (National Science Foundation, National Center for Science and Engineering Statistics, 2014) reveals that only 65% could correctly answer this probability question: *A doctor tells a couple that their genetic makeup means that they've got one in four chances of having a child with an inherited illness.* (1) *Does this mean that if their first child has the illness, the next three will not have the illness?* (No); and (2) *Does this mean that each of the couple's children will have the same risk of suffering from the illness?* (Yes).

It gets worse: Merely 34% could correctly answer a question about an experiment: (1) *Two scientists want to know if a certain drug is effective against high blood pressure. The first scientist wants to give the drug to 1,000 people with high blood pressure and see how many of them experience lower blood pressure levels. The second scientist wants to give the drug to 500 people with high blood pressure and not give the drug to another 500 people with high blood pressure, and see how many in both groups experience lower blood pressure levels. Which is the better way to test this drug?* and (2) *Why is it better to test the drug this way?* (We know, of course, that the second way is better because a control group is used for comparison.)

And even worse—only 20% could correctly answer this: (1) *When you read news stories, you see certain sets of words and terms. We are interested in how many people recognize certain kinds of terms. First, some articles refer to the results of a scientific study. When you read or hear the term scientific study, do you have a clear understanding of what it means, a general sense of what it means, or little understanding of what it means?* and (2) *In your own words, could you tell me what it means to study something scientifically?* (The failure to correctly answer this clearly indicates that people do not understand the principles that underpin formulating a theory/hypothesis and designing an experiment to test it or the role of control groups and the need for rigorous and systematic comparison.)

A research article in *Skeptic* by Walker, Hoekstra, and Vogl (2002) concluded:

> Students that scored well on these [science knowledge] tests were no more or less skeptical of pseudoscientific claims than students that scored very poorly. Apparently, the students were not able to apply their scientific knowledge to evaluate these pseudoscientific claims. We suggest that this inability stems in part from the way that science is traditionally presented to students: Students are taught what to think but not how to think. (p. 26)

Given that lots of people do not understand the way science works, what do we do to fix the problem? One solution suggested first by Carl Sagan (1996) and later by Shermer and Linse (2001) is that we provide students (actually everyone) with a Baloney Detection Kit. We want them to automatically ask 10 questions whenever they hear an unusual claim:

1. How reliable is the source of the claim?
2. Does the source make similar claims?
3. Have the claims been verified by somebody else?
4. Does this fit with the way the world works?
5. Has anyone tried to disprove the claim?
6. Where does the preponderance of evidence point?
7. Is the claimant playing by the rules of science?
8. Is the claimant providing positive evidence?
9. Does the new theory account for as many phenomena as the old theory?
10. Are personal beliefs driving the claim?

But how can we tuck these habits of mind into normal classroom exercises? To achieve this end, improved education and creativity at the K–16 level is important; this is where state and national standards and core curricula come into play. How that scenario will end up is yet to be determined.

What about those of us in higher education? Is there anything that we can do to improve the situation? It appears that we have at least three populations of students. One group is our STEM majors. We tend not to worry about them. It is true that there is evidence that suggests that the more science courses and lab experiences they have, the more they understand the facts as well as the process of the scientific enterprise. But here is a caveat: The process of indoctrination to the canons of science takes a long time, and there are many dropouts along the way. How much do our graduates really understand about how to evaluate the "science" of today as it is filtered by the modern media?

What about our preservice science teachers headed for the K–16 classrooms? They will be in the front lines, but many of them are poorly prepared to grapple with STEM subjects they have only taken one course in, which most likely was delivered by a traditional lecture. Unfortunately, 86% of most introductory science courses are still delivered this way, a medieval presentation method created at a time when we didn't have textbooks, film, or the internet. STEM majors may survive this indoctrination with their enthusiasm intact, but many others who may end up teaching our children may not. Again, just more science doesn't make someone immune to pseudoscientific claims (Walker et al., 2002).

Here is the big question: How do we deal with the overwhelming number of students who take science courses because they have to? I have the impression that many of my colleagues are really dismissive of these students; they are not potential graduate students. We usually have only one shot at nonmajors, one or two semesters in a general education course, and then they are free to roam the media world littered with alien abductions, Sasquatch sightings, homeopathic remedies, probiotics, magnetic bracelets, and the latest health benefits they just heard about on the *Dr. Oz Show*.

The faculty at Sam Houston State University in Huntsville, Texas, has come up with a promising antidote to the lack of critical thinking by designing a course for nonmajors that seems to fit the bill (Rowe et al., 2015). This general education and interdisciplinary course, called Foundations of Science, "emphasizes the nature of science along with, rather than primarily, the findings of science; incorporates case studies, such as the vaccine-autism controversy; teaches the basics of argumentation and logical fallacies; contrasts science with pseudoscience; and addresses psychological factors that might otherwise lead students to reject scientific ideas they find uncomfortable" (Rowe et al., 2015, p. 1). Their approach is to try to inculcate in students the operational approach to critical thinking provided by Bernstein, Penner, Clarke-Stewart, and Roy (2006). When presented with claims such as vaccines cause autism, global warming is a hoax, and there are no transitional fossils, one should ask: (a) What am I being asked to accept? (b) What evidence supports the claim? (c) Are there alternative explanations/hypotheses? and finally, (d) What evidence supports the alternatives?

Sam Houston State University chose to focus on pseudoscience because the topics are inherently interesting even to science-phobic students: astrology, homeopathy, Bigfoot, and intelligent design. They adopted a textbook that emphasizes the same approach: *How to Think about Weird Things: Critical Thinking for a New Age* (Schick & Vaughn, 2014). A key feature in their curriculum is the use of two case studies. The first deals with the claim that vaccination is a cause of autism (Rowe, 2010). The students work in small groups and analyze the data provided in a study by Wakefield et al. (1998). Then they are asked to design a better study and in the process learn about experimental design and sample size, replication, double-blind studies, and scientific honesty. In another case study published recently in the *Journal of College Science Teaching* (Rowe, 2015), the authors apply ecology theory to evaluate the credibility of finding a plesiosaur moonlighting as the Loch Ness Monster. This case is especially interesting because it integrates traditional scientific facts and principles along with a skeptical approach to fantastic claims, illustrating how important it is to consider alternative hypotheses to unproven claims, especially those that verge on the incredible.

So here is my pitch: We need to do a much better job of teaching everyone how science actually works. This is the same sentiment that James Conant carried with him back to Harvard at the end of World War II, after his term of service as science advisor to President Franklin Roosevelt. While in this position, Conant became convinced that the American public just didn't understand the process of science. He set out to remedy this, at least with Harvard students, by teaching a course, Natural Science 4, "On Understanding Science." Four years later, he began teaching another undergraduate course, Philosophy 150, "A Philosophy of Science," which led to the famous text published in 1957 titled *Harvard Case Histories in Experimental Science.* As far as I know, this was the first formal attempt to use the case study approach to teach basic STEM topics.

We have no record of how the students at Harvard in Conant's classes received this new approach telling the detailed history of the major scientific discoveries. Surely, the subject matter was better digested than the previous method of delivering endless facts to nonscientists. However, Conant's case studies were all delivered via the lecture method, the least effective method for teaching (Lord, 2007). Unfortunately, the lecture is still favored by STEM teachers today in spite of a mountain of evidence, suggesting the method is a major reason that 60% of students who enter college intending to major in a STEM field fail to graduate with a STEM degree (see, e.g., Gates & Mirkin, 2012).

There are hundreds of studies concluding that active learning strategies like cooperative and collaborative learning produce greater learning than the lecture method (see, e.g., Hake, 1998). But we faculty appear too set in our ways to easily give up the technique where we ourselves excelled. It is a Darwinian process. We managed to learn via the lecture method and so we expect our students to do the same. We are the survivors, the ones who stayed in the system. What about the crowd of students who dropped by the wayside, not necessarily because they didn't do well, but as Sheila Tobias (1990, 1992) wrote long ago and the President's Council of Advisors on Science and Technology (2012) declared recently, they quit STEM disciplines because of uninspiring introductory courses, the math requirement, and an academic culture that is unwelcoming (Gates & Mirkin, 2012).

All of this then gives me a strong platform from which to argue that the methodology of science is best taught via active learning using the case study method. Using stories (true ones are best) puts the science in context (Herreid, 2007). There are two obvious ways to do this. One is to showcase scientists actually going about their daily business of making discoveries—detailing their mishaps and struggles to solve a problem. The website iBiology (www.ibiology.org) attempts to fill that need. They have a growing collection of more than 275 videos by scientists talking about real cutting-edge scientific research and topics related to science.

Another approach is to use written case studies, a method championed in this column and promoted by the National Center for Case Study Teaching in Science (http://sciencecases.lib.buffalo.edu/cs/). Our collection has over 600 STEM case studies, many emphasizing scientific methodology: Watson and Crick puzzling over how DNA replicates, Warren and Marshall battling to convince the medical establishment that bacteria are the major cause of ulcers, epidemiologists hunting for the reservoir of the Ebola virus, and citizens debating the legalization of marijuana are just a few examples. Further, we are treated with mini-mysteries such as when statistician Ronald Fisher was confronted by a woman who claimed she could taste whether tea was prepared by adding milk before or after the tea was poured in the cup and a little puzzle about a spa that advertised that their foot bath would remove the toxins from customers' bodies (McCallum & Prud'homme-Généreux, 2016). Big or small, these tales are the stuff of challenging classroom exercises.

Case studies have the potential to correct many misconceptions that a layperson might have about science. One common false impression is that scientists are lonely recluses working out the wonders of the world in a dingy laboratory waiting for the "aha" moment to rush out into the street shouting "Eureka." If that were ever true, it certainly isn't true today, when research teams and joint publications are the rule. We can have 45 authors contributing to the discovery and analysis of the fossil *Ardipithecus* *ramidus* or in physics publications with over a thousand authors. Even teachers may neglect the role that scientific society as a whole plays in the discoveries, especially the part that peer review plays. This is a vital point for students to learn, and a case study can illustrate the process powerfully. Only by understanding the checks and balances in the scientific enterprise can the public get a sense of how seriously researchers take their jobs and can they gain confidence in science. So when 97% of climate scientists say that climate change is upon us (Stern, 2015), we would hope that the public would accept this is a fact that we had better act on.

Perhaps the best way that the scientific process is in full display is when misconduct is discovered. Seldom is it an outsider that pulls back the curtain on inappropriate conduct; it is scientists themselves who normally discover unsavory business. One of the best examples is when Stanley Pons and Martin Fleischmann claimed to have discovered cold fusion, a process of energy production with a promise to satisfy the world's insatiable desire for cheap energy (Taubes, 1993). In a laboratory at the University of Utah, these respected investigators asserted they produced a nuclear reaction on a table top. Before publishing their findings, they bypassed the usual vetting of their experiment in a journal review process and held a press conference touting their spectacular claims instead. Then they delayed giving important details of how their work was accomplished. This created a firestorm of criticism. Many investigators tried to replicate their work. All failed. Soon it became apparent that their claims were more than doubtful. Pons and Fleishmann's careers took a nose dive. They had not followed the usual canons of science and as a result payed a personal price. The story did not have to end this way. If they had followed normal protocol and submitted their findings to their colleagues, criticism would have been confined to the scientific community and reviewers would have been able to identify the possible errors before going public. That is one moral of the story: There is a good reason that we have the critical and analytical process that we have, to prevent just these kinds of errors.

Case studies like these are an ideal way for students to get a true taste of what goes on with us scientists. These are cautionary tales. Rather than showing the fallibility of scientists, they illustrate how hard we try to find out the truth. Criticism is one of the safeguards of the process and is a key part of the self-correcting nature of science. Case studies are an ideal way to showcase the beauty of the process. Whatever techniques we teachers choose to use, we have an obligation to help rectify the problem of scientific illiteracy in our students before they head into the world of Loch Ness Monsters, astrology, chiropractors, and acupuncture. ■

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