I exchanged private e-mails with Helen Quinn shortly after our writings appeared in the same issue of PHYSICS TODAY. She wrote that her "impression is that the idea of a law became archaic right about the time it was realized that Newton's laws were not absolutely true in all circumstances. But we never gave up using the term for ideas that had already been blessed with that language usage." She asked, as does William Hooper, who would decide, and whether some international body of physicists should be empowered to promote theories to laws, just as the International Astronomical Union declared that Pluto is not a planet. I agree with that proposal, but I'll caution that Pluto is still a planet to me.

Hence, I make my own prejudice clear as to theories versus laws. Unlike Gregory Mead, Joseph Ribaudo, or Lewis Wedgewood, I find the idea of a law much more compelling than a theory. In my own corner of physics—elementary-particle or high-energy physics—we have, for example, string theory and supersymmetry theory. Although both propose solutions to perceived problems with the standard model of high-energy physics, neither has made a prediction that has yet been verified by experiment. (My theoretical colleagues will disagree, and they will happily point out that in supersymmetric theories, in which every quark, lepton, and gauge boson we currently know acquires a new partner, about half of the supersymmetric particles have already been discovered. Some may argue that the observation of "dark matter" is actually the detection of supersymmetric particles, but to me the connection has not yet been made.) Furthermore, in casual conversation, private thinking, or everyday life, one frequently hears—or asks—the question, "Does it violate the laws of physics?" I've never heard "Does it violate the theories of physics?" I vote for the laws of special relativity, and in deference to history and the input from readers of my letter, let a duly organized body of physicists assign attribution, lest others do it for us.

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## Language of science II: Degrees of knowing

Helen Quinn (PHYSICS TODAY, January 2007, page 8) makes a very good point that the general public often misunderstands the meaning of "belief" and "theory" as used by scientists. The problem originates, I believe, in the way science is taught in the schools. As Thomas Kuhn noted long ago in *The Structure of Scientific Revolutions* (University of Chicago Press, 1962), science is taught like religion: You'd better believe it or you will get a bad grade. Fundamentalists opposed to evolution have a stronger threat: You'd better not believe it or you will go to Hell.

Today, as a result of the No Child Left Behind Act, US public schools place increased emphasis on testing. Unfortunately this motivates teaching to the test, with little emphasis on the scientific method.

The most important thing to be taught is how scientists have come to believe the present theories, usually after a long struggle, as a result of many experiments and observations. Even for a limited part of physics, it is hard for a student to recapitulate in a semester what may have taken scientists many years to discover. There is always an attempt to cover too much material, as evidenced by the weight of the latest university physics textbooks, which only the stronger students can lift. There is no simple solution, but it is important to identify the problem.

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**Thank you, Helen Quinn!** Many physicists need your reminder to watch some of the words we use in our discussions. As teachers, we must be especially careful; and when we talk with nonscientists, it may well be necessary to explicate exactly what we mean by certain words. The majority of the population is not even aware of the incorrect meanings so many people attach to so many significant words.

The recently renewed debate on biological evolution provides a wealth of glaring examples. People often misuse words in important discourse. As a hopefully extreme example, I recall the claim: "I know that God exists, but science is only a bunch of theories." At the same time, people enjoy the use of the most sophisticated gadgets that recent science and technology has made available.

I suggest that the understanding and distinction of the correct meaning of words such as knowledge, belief, hypothesis, and scientific theory must be an essential part of education. It should be taught in all high schools—if not in earlier levels. Those who do not have the benefit of a college education also participate actively in public discussions debating vital political issues. In a democracy, these people also vote, or should vote.

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**I couldn't agree more** with Helen Quinn that words should be chosen carefully when expressing the level of certainty regarding knowledge of physics. However, if the goal is to maximize the credibility of scientific communication, I think we should not overstate the case for that certainty.

Underlying our ability to obtain knowledge about the physical world are a few assumptions that must be taken as fundamental and are not actually tested by our experiments. One is the inductive principle that our observations can be generalized to obtain the laws of nature. A second assumption is that researchers' memory and testimony are reliable. Quinn states a third: that physical laws are universal and immutable. The truth of these assumptions—or our ability to know their truth absolutely—has been questioned by various philosophers.[1] Many theologians would take issue with the last one. In fact, nonscientists could correctly label all three as beliefs, articles of faith held by those with a scientific mindset, in the same way that people hold beliefs in other areas of human thought.

Quinn's statement that "we know that protons and neutrons are composed of quarks and gluons" is an example of wording that is too strong. How do we know there is an underlying reality to this theory? Or is it simply a mental model consistent with our experimental results?

Practically speaking, nonscientists' judgments are influenced by conclusions presented in all of science, not just physics, even though we physicists may be tempted to think that our knowledge is more certain than, say, that of researchers in biology or medicine. When a person reads reports that red wine or coffee is good or bad for human health, that a flu pandemic is imminent, or that it is going to rain tomorrow, a certain amount of skepticism may be justified. Implying that results in physics can be known with absolute certainty opens up physicists for criticism as dogmatists and may lead to mistrust between scientists and the general public. Many readers of popular science are willing to accept research results if they are presented in a manner that does not encroach on their religious or ethical beliefs. To be credible, physicists need to make sure their conclusions are stated with the appropriate level of conviction.

## Reference

1. See, for example, B. Russell, *An Outline of Philosophy,* G. Allen and Unwin, London (1927).

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**I was pleased** to learn I was not alone in my concerns about how "theory" and "hypothesis" are interpreted by the general population. The call to be more careful in how we present our debate and consensus to the public is an excellent point. I would add that the recent debate over Pluto should have been handled just as carefully. To the public, scientists can't even agree on what is a planet and what is not.

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**Quinn replies:** The range of responses in a way illustrates my point: Words mean different things to different people. If we wish to be understood we must explore the meaning our listener is taking from what we say, and not just repeat our words. I doubt that elevating certain theories by calling them laws will help, though my suggestion that we say we know these things has a similar didactic bent. In the end we can only attempt to communicate better and, as Lincoln Wolfenstein points out, to do a better job of education about both the power and the limitations of scientific knowledge.

"Know" and "knowledge" are just examples of words that have different meanings in everyday usage, in the discourse of scientists, and in that of philosophers. I think most people are quite happy to say they know that the Sun will rise again tomorrow, though from a philosophical point of view that is merely a well-grounded hypothesis. When I recommend that we say we know some things based on well-established scientific theories, I am suggesting that for the sake of better communication, we accept our audience's idea of what it means to know something. I disagree with Fritz Rohrlich that we must teach the "correct meanings" of words. One usage is no more correct than another, language being a fluid thing. Instead, we must be willing to carry on the discourse long enough and with enough respect for our audience, be they students, interested members of the public, or other scientists, that we come to a shared understanding.

All our scientific knowledge rests on a set of conjectures or postulates that we cannot prove a priori; in this I agree with Kurt Huddleston. I argue, and I think he would agree, that a posteriori, these provide a very useful way to interpret the world around us. This approach has led to many medical and technical developments that we now depend on, as well as deep and interesting insights of a less practical nature. What one concludes about the world certainly rests on the assumptions one takes as primary. There is a direct contradiction between the conclusions from certain versions of religious belief, particularly those based on the belief that the Bible presents literal truth, and scientific conclusions about evolution, whether of the universe or of the species that populate Earth. When a student struggles with that contradiction, we should acknowledge and respect the struggle. We cannot avoid the contradiction; instead we should admit it and continue down the path of science, presenting students not only with its conclusions but with its primary assumptions, and with some understanding of the multiple strands of evidence that support the scientific conclusions given those assumptions.

Thus I argue that we should teach science as science, and religion as religion. When we teach science, we need to do the best job we can of teaching both fundamental assumptions and practices and the conclusions to which they have led us. The key idea that experiment and observation are the arbiters of scientific conclusions differentiates the scientific worldview from others. That idea certainly has a power of its own. In the modern world, every student should have the chance to learn about it. Informed decisions on issues that involve scientifically derived information can only be made by consumers and citizens equipped to judge the value—and the uncertainties—of that information. Our job as science educators and communicators is to make the scientifically equipped portion of the public as large as possible. It is no mean task, and we do not achieve it better by disrespecting either the intelligence or the beliefs of those with whom we wish to communicate.

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