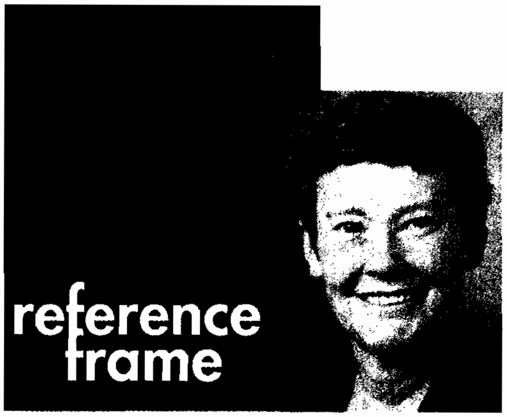

Belief and knowledge—a plea about language

Helen Quinn

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I remember the puzzlement of a friend as my husband described his thesis research—a coincidence experiment. His listener stopped listening; she was thinking about why anyone would try to measure coincidences. I pointed out that the word "coincident" simply means "occurring at the same time." The experiment used its precise timing to ensure that two particles detected at the same time had a very high probability of coming from the same source event. Thus the term coincidence was used in a sense opposite to the everyday meaning, where a coincidence is two uncorrelated events that come together. Words shift their meaning; each community develops its own usage. That change in meaning leads to miscommunication.

A few words in elementary physics—force, work, momentum, and energy—have carefully defined physics meanings. Their much broader everyday usage causes students a great deal of confusion until they learn the precise physics concepts. Rather than belabor such cases, I will focus on some words that are, I think, the root of considerable public misunderstanding of science: belief, hypothesis, theory, and knowledge.

None of these words has a unique physics meaning, but their meanings as we use them among ourselves and as nonscientists hear them are very different. We need to be much more careful how and when we use them in talking to the public.

Belief and knowledge

For most people a belief is an article of faith, a hypothesis or a theory is not much different from a guess, and as for knowledge—well, that is not very different from a belief, except that most people are much more certain of what they believe than of what they know. Another usage of belief, as in "I believe he is coming at 5:00pm," has no sense of faith—in fact, quite the contrary. It contains an implicit "but I'm not really sure." When a person hears "scientists believe," he or she may hear it as a statement of faith or a suggestion of uncertainty. Neither is what we intend.

What do we mean by "scientists believe that . . ."? Typically it is something like "Most scientists agree that the preponderance of the evidence favors the interpretation that . . . , and furthermore, there is no evidence that directly contradicts that interpretation." Clumsy language perhaps, but it would behoove us to say something like it more often. If we need a shorthand version, we can replace it by "Scientific evidence supports the conclusion that . . . ." Sometimes we should just say "We know that . . . ." In other words, we need to articulate more precisely the state of our knowledge—its authority or uncertainty.

Any good scientist has a conscious range of knowing, from established fact to hunch. We continually reevaluate the status of ideas along that continuum. We serve science poorly when we either over- or underclaim the confidence with which we know something. One of the things that makes us scientists is our intricate examination of knowledge—our understanding of what we know, of how we know it, of what evidence supports it, and of the limits of that evidence. This conscious continuum of knowledge certainty is poorly understood by most listeners, but is taken for granted when we converse amongst ourselves.

When talking amongst ourselves we should also be more careful what words we use. Otherwise we might slip when talking to the public, and say we believe something when we mean something quite different from the everyday usage of the term—and the trouble begins. If scientific belief is set against other beliefs, what differentiates it from them—are we not then just arguing matters of faith? The US has a strong current of religious tolerance. Even people strongly identified with their religious faith will defend the right of others to follow other faiths, misguided though they may think those faiths are. "OK, that's what you believe, but I believe something different." A belief is not convincing to others, even when strongly held. If we set up science as just another belief system, we weaken its authority and dilute the power of our knowledge. If our "I believe" is heard in the sense of uncertainty, that weakens the strength of our assertion even more. We could, and I think should, excise the word "believe" from our vocabulary when talking about science.

Nonscientists are often remarkably ambivalent about the idea of a fact, other than those that can be deduced from direct observation. My measure of this is the airplane conversation. Usually a taciturn traveler, I prefer to bury myself in a book rather than strike up a conversation. If by chance I say I am a physicist, I often get drawn into a cross-country conversation about particle physics and cosmology; my listeners ask question after question. Somewhere along the way, they will say something like "This is fascinating, but how can you really know these things?" When I talk about evidence and how we know anything, I quickly find that my listeners, though interested in and possibly even quite knowledgeable about scientific ideas, have a weak sense of a chain of logic and inference supported by cumulative but not direct evidence. They typically do not recognize that this same kind of inferential knowledge—what any scientific theory really is—allowed inventions that everyone uses every day.

I can know that if I hold out a rock and let it go, it will fall to Earth. My listeners will agree. They will even accept that I can use my knowledge of gravity to predict the way a satellite will travel. But that I can use the knowledge to infer the existence of unseen matter in a distant galaxy seems preposterous to them. Of course, at one level they are right, what I can infer is either that there is unseen matter (dark matter) or that the laws of gravity must be modified to explain the data. But my listeners seldom accept that I cannot just introduce a modification of gravity for the distant galaxies and leave the laws of gravity the same for predicting satellite motion. They have no sense that the universality and immutability of the fundamental laws is the basic postulate of all science. No matter how many tests have shown us that the laws of physics do not change with time and place in the local region around Earth, how can I assert that I know these laws apply elsewhere in the universe? Again, I must argue from a chain of inference, from self-consistency, and, if you like, from Occam's razor—it is superfluous to introduce new laws to explain distant observations when existing laws can be used.

Interestingly, nonscientist listeners find no mystery in the fact that the laws of gravity are the same in Paris and Melbourne, but they hesitate to extrapolate from that to the entire universe. Stranger yet, when they read that scientists discovered a planet orbiting a distant star, they accept that news. The distant planet was not seen either—it was inferred from the motion of the star and the laws of gravity. However, language is loose enough that the report might even say that "scientists have seen," or more likely "scientists have discovered," the planet. Apply the laws of gravity to discover something as mysterious and hazy as a cloud of diffuse dark matter, matter that cannot be seen, with properties different from anything we have seen, and the report and its acceptance are quite different! What inference is acceptable has more to do with how natural or strange the conclusion seems to the listener than with the nature of the chain of logic.

Without the postulate of the universality and immutability of the laws of nature, I do not even know that the Sun will rise tomorrow morning. Without the validity of that postulate, there would be no point to doing science! How does such a postulate differ from a belief? In science the essential point is that every idea has a tentative nature—if data tell us we are wrong, we must give up that idea. A belief, on the other hand, is typically not subject to test; it must be taken on faith.

The existence of universal scientific laws is certainly an effective postulate—so much can be predicted and understood based on its application. This postulate is tested over and over again, whenever a scientific prediction works or a scientific discovery allows new technologies or new medical treatments. It has worked so well and in such varied domains that we can say it is no longer just an assumption, but an observed fact over a wide range of space and time. That postulate allows us to seek a model for the history of the universe that is consistent with everything we know about the laws of physics. Remarkably, when we try to do that, we find properties of the universe and of physical laws that we did not expect. We also keep probing the limits of validity of the postulate. Do the "constants" of nature change slowly over time? Is there evidence that requires us to conclude that some do? Of course, if we find such evidence, we will try to develop a new universal theory that includes the variable as part of the dynamics rather than as a fixed parameter. We will not readily abandon the fundamental postulate that there are underlying universal laws! It has already been far too successful.

Hypothesis, model, and theory

We also use "theory" in a way that is far from the everyday usage (where a theory is pretty much a hunch), particularly when we talk of "the theory of . . ."; examples are relativity, electromagnetism, evolution, plate tectonics, the standard model of particle physics. (Now there is a strange historical accident of language—the well-established theory of particle physics was once one model among many. It became known as the standard model as test after test confirmed its predictions. Usually we use "model" for ideas that are less well established.) These theories are far from guesses; they will survive no matter what new evidence is accumulated. They are complex constructs that incorporate and explain a significant body of evidence. They have demonstrated predictive power as well as descriptive power.

We also know that they are not complete. Although they are well tested in some domains, in others uncertainties remain about their detailed application. Indeed, we expect that they will be modified or extended to explain new evidence. But they will not disappear, just as Newton's laws did not become invalid when we understood special relativity, but rather were seen to be a very accurate approximation under well-defined conditions. Theories such as those listed in the previous paragraph are strong enough that we can use them to say we know certain things—we know that protons and neutrons are composed of quarks and gluons, we know the relationship between mass and energy, we know that Earth's surface is not a single rigid structure. These are facts, but not just simple observational facts. They come from the amalgam of observation and theory development and testing that is the essence of scientific knowledge development. It diminishes the status of our understanding greatly to say that scientists "believe" these things. We know them!

When we seek to extend and revise our theoretical frameworks, we make hypotheses, build models, and construct untested, alternate, extended theories. These last must incorporate all the well-established elements of prior theories. Experiment not only tests the new hypotheses; any unexplained result both requires and constrains new speculative theory building—new hypotheses. Models, and in the modern world computer simulations too, play an important role here. They allow us to investigate and formulate the predictions and tests of our theory in complex situations. Our hypotheses are informed guesses, incorporating much that we know. They may or may not pan out, but they are motivated by some aspects or puzzles in the existing data and theory. We actively look for contradictions.

Particle physicists look for data that do not fit standard-model predictions. They suspect this theory needs extension and want evidence of what direction to look for that extension. Whatever they learn will not cause quarks and gluons to be discarded. Geneticists are perhaps revamping the early stages of the tree of life into a more complex set of interconnections, but the later branching that is well established will not be invalidated by any such development. Theory evolves and changes, but the change is rarely revolutionary. Even the truly new developments such as quantum physics or relativity do not completely replace what was known; they just delimit its domain of applicability.

The science press and scientists themselves do science a disservice when they seek to dramatize a discovery by emphasizing that it discredits a previous theory. Such coverage typically does not discuss whether the earlier theory was tentative or whether the new result modifies a well-established but incomplete theory. This dramatization feeds the popular image that all scientific knowledge is tentative. Much is tentative, but much is well understood and unlikely to be discredited. We scientists need to convey more about the status of our knowledge than can be learned from the muddy "most scientists believe" statement. We need our listeners to know what is tentative and what is not so that they understand better the ragged but cumulative progression of science and can use current knowledge effectively, with an understanding of its inherent uncertainties, in personal and political decision making. ■