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Getting a Kick Out of Epistemology

Why deep epistemology is essential in secondary science education

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Open any text published by Centripetal Press and you will find an extended treatment on the nature of scientific knowledge. In our middle-school text *Physical Science*, this subject is treated in a full chapter right in the middle of the book, with a discussion on facts, theories, hypotheses, and—importantly—several sections on the relationship between scientific knowledge and truth.

Nearly all science texts discuss some aspects of epistemology, even if it's just by way of a standard presentation of the so-called "scientific method." Many texts go into more depth and address the roles of theories and hypotheses in scientific research. But educators new to the deeper approach taken by Centripetal Press may wonder why epistemology is treated so prominently in our materials. Why do we get such a kick out of epistemology?

Motivator #1

To begin, one of our primary motivations is to clear up confusion, that is, *to teach*. Scientists have remarked for decades that very few American adults understand the nature of scientific knowledge. In particular, Americans generally do not understand what theories are, the role they play in scientific research, or how to speak of them properly. An eyebrow-raising example of this confusion I once came across was a statement in a curriculum guide at a private school. The guide was for a 4th-grade unit on evolution, and the statement read, "Remember, no theory is true until it is proven."

Well, to quote a speech I once heard, there are more errors than words in that statement! For starters, just on a logical level, a truth is true regardless of whether anyone ever knows it or proves it. But more to my point here, theories are not truth claims; they are models. We do not have access to complete, certain, true knowledge of physical reality, so we build models—mental models, that is—of reality to organize what we know and how that knowledge fits together. Models are not true or false; it is not even coherent to speak of them this way. A given theory is perhaps useful, and perhaps accurate, but scientists do not regard it as truth. They regard any theory as an explanation (or model, or representation) for the facts in some part of the natural world. A widely accepted theory is regarded as our best such explanation.

Second, theories are never "proven," any more than any model is proven. Again, the concepts here are not even coherent. How does one prove a model of a battleship? What would that even mean? A model may be made more accurate, more detailed, or more inclusive, and it may be tested again and again to discover how accurate it is, but one doesn't prove a model.

Another aspect to the prevailing confusion is that people commonly refer to theories as if they were merely hunches, as in, "You don't have to believe that; it's just a theory." But theories are not hunches or wild guesses and it is not appropriate to speak of a widely accepted theory in this dismissive fashion. In fact, I like to say that successful theories are the glory of science and developing them is the goal of scientific research.

Yet another aspect to the confusion is that people tend to use the terms *theory* and *hypothesis* interchangeably, even though they do not at all mean the same thing. A theory is a model that explains the known facts pertaining to a part of nature. A hypothesis is a prediction based on a particular theory; different theories lead to different predictions, and thus different theories represent the world with different degrees of accuracy. A hypothesis based on a particular theory is, in fact, the means by which we put the accuracy of a theory to the test. We develop a testable hypothesis from the theory and we test it. That's what an experiment is, a test of a hypothesis. If the hypothesis is confirmed, we don't say the theory has been proven. We say our confidence in the model has increased because it led to a correct prediction in one specific case.

Motivator #2

Helping to clarify the nature of scientific knowledge for students is a high priority for us. Related to this, a second reason for our emphasis on epistemology is the prominent place science has in contemporary society. Science and scientific knowledge are not exactly obscure branches of learning these days, as is, say, interpreting Etruscan pottery. Science and scientific knowledge are such a central part of contemporary life that a correct understanding of them is essential if people are to understand what's going on in the world around them. How can students participate in a discussion about climate change if they don't understand what a model (theory) is, or even why a theory is a model, or what it means to accept a model based on a persuasive amount of evidence (interpreted data)? How can students be equipped to deal with the conflict between what mainstream science tells them about the age of the earth and what some anti-science religious groups are telling them? And, although this is less a part of the discourse in the popular media, how can students appreciate scientists' concern over the fact that the general theory of relativity conflicts with quantum mechanics—the two most successful scientific theories of all time—unless they understand that all theories are provisional and subject to revision?

Confronted as we are with issues such as climate change, ocean acidification, cancer research, acid rain, the latest dietary advice, budgets for research on exoplanets, deforestation, treatments for genetic diseases, and threats to the integrity of our food supply, how can students become adults who can function adequately in a science-driven culture unless they understand what science is and the nature of the statements scientists make?

Motivator #3

A third reason for our insistence on the value of scientific epistemology for science education is our belief in truth. We deplore the fact that discussions about truth often tend to be ignored, avoided, or even mocked these days. We believe truth exists, and we are not afraid to talk about it, despite today's persnickety cultural climate.

Everyone knows that we humans are wonderfully endowed with inquiring minds and with a burning desire to know truth—the objective of an inquiring mind—and we are not doing our students any favors when we pretend otherwise. Good teaching stokes the fire and fans the flame of our students' desire for the truth and equips them to deal with it intellectually when they encounter it or its opposite.

In the context of science instruction, if students are not taught the difference between truth on the one hand and scientific knowledge on the other, their understanding of what truth is, what knowledge is, and what science is will be hopelessly muddled. To help illustrate the distinction, consider some statements made by famous scientists. The first was made by renowned chemist G.N. Lewis in his 1925 Silliman Memorial Lectures:

> The scientist is a practical man and his are practical aims. He does not seek the ultimate but the proximate. The theory that there is an ultimate truth, although very generally held by mankind, does not seem to be useful to science except in the sense of a horizon toward which we may proceed.

I very much appreciate the metaphor of truth as a horizon toward which science may proceed. This way of thinking about the relationship between truth and scientific knowledge emphasizes the fact that we understand what we currently know—the facts and theories of science—as provisional and subject to change as we learn more. Truth, by contrast, is the way things really are and is thus not subject to change. Hopefully, continued research leads our scientific theories closer to the truth—that distant horizon—but even this is not certain. In a paper responding to Thomas Kuhn's famous book, *The Structure of Scientific Revolutions*, Nobel-Prize winning theoretical physicist Steven Weinberg commented that we cannot even say for certain that our theories are getting closer to the truth. Of course, we hope our theories are getting closer to the truth, but we have no way of knowing with certainty.

Danish physicist Niels Bohr once made the following comment:

> It is wrong to think that the task of nature is to find out how nature *is*. Physics concerns what we can *say* about nature.[1]

This statement is profound, and unpacking it completely is not a task we can take on here. But I quote it because of the clear distinction Bohr makes between the way nature really is (the truth) and our ways of talking about it. When we speak of nature, we are describing our own models—theories—which represent our best understanding at present of the facts we have. All of it evolves as we learn more; all of it is provisional.

The scientific enterprise has obviously been successful on a dazzling scale. We understand nature well enough to put men on the moon, design lasers, fabricate nano-scale semiconductors, and treat tumors without surgery. But great scientists always admit the humility we need to bring to our scientific achievements. We do not know how close our theories are to the ultimate truth of nature, but our thirst for the truth continues to propel us forward in search of a deeper understanding of the world.

Let's consider one actual example from science, atomic theory. This theory was not widely accepted until the late 19th century. The atomic theory holds that all matter is composed of tiny particles called atoms (or parts of atoms). According to the theory, atoms themselves are composed of protons, neutrons, and electrons, and protons and neutrons are understood to be composed of even smaller particles called quarks.

The atomic theory is obviously another very successful theory. It is the universal basis for instruction in chemistry and physics. But is all matter really composed of tiny particles? Many physicists think that matter may instead be composed of strings, or membranes, or structures in 11 or 13 spatial dimensions. And truth be told, the smaller particles inside atoms, such as electrons, can only be described metaphorically. Cuing off Bohr's comment quoted above, we can *say* that electrons exhibit particle-like characteristics. We can *say* they exhibit wave-like

1 Reported by Aage Petersen in "The Philosophy of Niels Bohr," Bulletin of the Atomic Scientists 19(7) (1963), p12.

characteristics. And there are many other things we can say about electrons. But no one can say what an electron is. We know a few mysterious facts, some of which will likely be found to be incorrect in the future. We do not know the truth about electrons.

Motivator #4

Finally, we are driven to treat epistemology in our texts because we care about students as human beings—as people. We do not view school simply as job training or career preparation. Science "education" that never rises above describing magnetism, momentum, stoichiometry, and DNA is unworthy of the human mind. The potential of most students' minds is far beyond what they are ordinarily expected to achieve in any course of study. We believe that teachers should help students explore the world around them and lead them in trying to understand it more deeply year after year. We want students to revel in just how remarkable, and wonderful, the world is. We want them to be fascinated by the whole notion of the meaning of human achievement. We want them to know that life is not just about getting a job and consuming products—there is so much more, and they can be a part of it!

Equipping Students

Our company is obsessive about ensuring that the scientific presentations in our texts are as lucid, engaging, and accurate as possible. But we also want students to experience the joy of seeing how what they are learning in their science class relates to their lives in general and to their growth as people with minds, maturing human beings in the world. We want them to be equipped to think philosophically about what we know, and to understand that when it comes to our scientific understanding of the world, what we know today could change tomorrow.

Science is not simply about memorizing endless lists of facts. It is a process that leads to knowledge of a particular type. Getting a grip on how this kind of knowledge differs from other kinds of knowledge is crucial to understanding what science is and what scientists are saying when they make scientific statements. And understanding this requires epistemology.