

LETTERS

Teaching, Propaganda, and the Middle Ground

Is it true that teaching introductory modern physics is primarily propaganda? The Opinion by Mano Singham (PHYSICS TODAY, June, page 54) takes the dictionary definition of the word, broadens it to include a system of data and deductions, and then uses it in its pejorative sense. His argument falls into philosophical relativism, which unfortunately seems to have become doctrine in the politically correct world in which any opinion has the same value as any other opinion. It seems to me—a quantum (and philosophical) realist—that informed opinion is more valuable than uninformed, and experiment-based systems are more valuable than belief-based ones.

Doug, Singham's student who still didn't believe in relativity, may or may not have a problem. If he is saying that he is not sure whether general relativity is the whole, precise answer (to some question), that is the critical thinking Singham is aiming for. If he does not believe that time dilation occurs, one is reminded of a response attributed to Richard Feynman. When a grad student said he "really didn't believe in quantum interference," Feynman told him to go do the experiments until he believed it!

It is not logical to leap from unquestioning acceptance of all experts to the dubious virtue of always challenging authority and taking unpopular views. Since the 1960s, it has seemed fashionable to assume authority wrong because it is authority, and to feel that, if someone is not precisely correct in some particular, all his or her statements are self-serving lies. Unfortunately, blindly rejecting authority can lead to the same types of problems as blindly following it. Challenging proof, demanding understandable explanations (while pursuing knowledge to further understanding), and

rigorously analyzing arguments are the stuff of intellectual curiosity and progress. Refusing to believe when you don't know any more than the other person seems to me to be oppositional rather than intellectual.

The Kansas State Board of Education, creationists in general, and Jamal (as described by Singham) are not particularly shining examples of critical thinking, careful weighing of evidence, intellectual curiosity, and rejection of intellectual coercion.

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Mano Singham's article raised the insightful observations that many students accept physics theories without critical examination and that, in many cases, physics teaching is like propaganda. I agree that, to promote critical thinking, it might be helpful for us physicists to encourage skepticism of what we say. However, the selective rejection of well-founded scientific theories on the sole basis of personal religious belief does not constitute critical thinking. To be a critical thinker, one must subject all scientific theories to the same test. Although fluid dynamics may not conflict with one's own religious belief, it should not be accepted without question. Although evolutionary theory may conflict with one's belief, the evidence must be weighed objectively. That so much more skepticism surrounds evolutionary theory than other scientific subjects shows both a lack of critical thinking and widespread irrational religious fundamentalism.

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I do not doubt Mano Singham's good intentions, nor his desire to provide the best science instruction. But his assumptions contain major flaws that run counter to science.

Science does not operate through belief but through proof, experimental and mathematical. Once proof has been achieved, belief becomes irrelevant. Therefore, it is not neces-

sary to "achieve belief" or to use propaganda for that purpose. What is important is to teach the fundamentals of the scientific method. Belief is antithetical to the scientific search for evidence. The believer is not concerned with evidence except as it reinforces the belief. The choice between believing in science and believing in pseudoscience is no choice at all. One should believe in neither, but instead look for the evidence. Even Galileo did not stand up for what he believed—he only stood up for what he could prove.

Because science is a collective, rather than an individual, endeavor, we can relate to scientific issues that are beyond our current comprehension. Specializing in applied optics, I have lost intimate contact with the physics and mathematics of cosmology, and I read the same popularized accounts that are available to the layperson. How then do I draw conclusions about cosmology? The answer is twofold. First, I accord my cosmology colleagues the same respect and skepticism that I expect from them. Their conclusions, published in reputable, peer-reviewed journals and not yet refuted, stand as the best that we currently know about the topic. Second, I do not necessarily accept these conclusions as ultimate truth, since even peer-reviewed conclusions must also pass the test of time. This may take decades or centuries, but eventually, a surviving theory is established as fact.

What distinguishes science from philosophy or theology is that the debate ends conclusively at some point. We know that Earth is not the center of the universe, and we can describe planetary motions through Newtonian mechanics and even apply relativistic corrections—such matters are no longer in doubt. If students cannot fully comprehend them, that does not mean that they are free to believe in alternative theories. That is what Singham should have told his creationist student, rather than saluting his independent spirit. Anyone ruled by a belief is the opposite of an independent spirit. And the students who accepted what Singham taught were not necessarily

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dolts, but perhaps they suspected that the conclusions of science were more likely to be correct than the pronouncements of pseudoscience. Perhaps they applied the same probabilistic judgment that we all must apply when faced with issues beyond our ken.

The corollary of the preceding is that teaching orbitals to 10th graders or the Big Bang to college sophomores is a bad idea. Students at those levels do not have the background knowledge to appreciate such concepts. "Introductory" modern physics courses wrongly pretend to be science courses. They should be thought of as liberal arts courses, in which the students receive a necessarily superficial overview to satisfy their curiosity about current topics and to expand their imaginations. Real science courses should be taught only when students have the background to appreciate and understand the material, not when they must accept what is presented by an act of faith. We need to remove fluff and reinstate rigor in science instruction. Otherwise, fewer and fewer people will be able to distinguish between the methods of science and those of creationism or other pseudoscience. And we scientists will have contributed by failing to understand and properly propagate the scientific method.

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I have been teaching a course called "Origin and Evolution of the Earth" to nonscience majors for the past 28 years, and lately I have come to share many of the same thoughts that Mano Singham expresses. We frequently tell our students that a distinguishing characteristic of science is its reliance on rational interpretation of empirical evidence, rather than on appeal to authority, as the pathway to truth. How ironic, then, that we expect students to accept on authority the conclusions that we or the textbook present.

I cannot agree, however, that creationist students who question the authority of science are more likely than others to "question authority elsewhere," or to "shake up the world and make it a better place." I have encountered many Doug and Jamals, and I am fairly confident that their rejection of scientific conclusions did not stem from indepen-

dent thinking on their parts, but rather from their prior acceptance of what other authority figures—pastor, Bible study leader, or parents, perhaps—had "brainwashed" them into believing.

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Cheers to Mano Singham for his article on teaching and propaganda. Science is a framework built around observations in nature. Scientists, including graduate students such as myself, are continually testing and evaluating this framework, but it is still a framework of reality and not necessarily reality itself. Religion and philosophy have as much to say about reality as science does, just not as much about measurable phenomena. Kudos to the students, faculty, scientists, clergy, and philosophers who keep a decent perspective.

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Bravo! to Mano Singham for his thoughtful Opinion piece. The course in modern physics—the third part of the traditional first-year calculus-based physics curriculum—is a very different creature from either of the other two parts. Physics was once called natural philosophy, but what seems "natural" in the first two physics courses is often torn asunder in the third.

We have few intuitions or personal experiences that directly bear on the problems of Albert Einstein, Erwin Schrödinger, Louis de Broglie, Arthur Compton, Enrico Fermi, and others. How do we go up against what other people believe, when we are asking them to believe modern physics principles based on our historical claims that the theories work and that the experiments suggest confirmation? The laboratory is an important part of the modern physics course, especially as it differs so much from other first-year lab exercises. But one still does not "find" the ratio of the electron charge to its mass any more than a mechanics lab "proves" Newton's second law.

Larry Opplinger at Western Michigan University has spent some time trying to come up with a simple, tabletop experiment for, say, a third-grade elementary classroom, to show both students and their non-physics-trained teacher that atoms exist. Of

my students who profess problems with cosmology or evolution, none seems to have any problem with chemistry. The stoichiometry of balanced chemical reactions, the limited number of elements, and the presence of the periodic table all require or at least suggest the atom. But where did our personal knowledge that atoms exist come from?

I bring up these issues of how and why we know what is true on the first day of the modern physics course. For example, certain students might want to know how they can reconcile the Big Bang theory with a fundamentalist religious upbringing. If this theory is "wrong," is all of modern physics "wrong" too? But cosmology is simply the result of applying what we know of physics to the description of a free-running, self-assembling system without outside interference. In any first-semester mechanics problem, we are always free to reset time to zero when we specify the initial conditions—even while the equations continue to describe behavior for times before the problem starts and for times beyond the end of the problem, no matter where the actual object is or what it is doing. Without arguing whether a literal reading of "creating the heavens and the earth in seven days" means the same thing today as it did when it was written, it is possible to have an individual belief of where the ultimate time zero occurs, with its own set of initial conditions, and still achieve some practical understanding from the results of modern physics. The 21st century will still be a world of semiconductors, nuclear reactions, giant particle accelerators, coherent phenomena, and wave-particle duality; our students need to have some understanding and appreciation of these things, even if most are not going to become physicists.

It is easy to say that we physics teachers do not teach "belief" because we are teaching science. It is not so clear-cut to the students—and sometimes to those of us teaching. And at the end of the day, like Singham, I am grateful to those who have spent the time to think about what they are being asked to think about, no matter their personal conclusions.

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The Opinion piece by Mano Singham raises some important points about teaching and propa-

ganda, but it misses some even more important ones. Having seen the creationist propaganda here in Kansas, I can say with some confidence that there are big differences between introductory science teaching and creationist proselytizing. Singham is correct that introductory physics courses ask students to believe scientific conclusions without adequate evidence. There is not enough time in the courses, nor do most students have the background needed, to follow all the evidence. Singham is also correct that we want students to apply critical thinking rather than to blindly trust authority. Still, I think he lets his students who doubt science off the hook too easily.

A strong response is needed from science educators when we see events like the Kansas State Board of Education letting creationists rewrite their science standards. (For an update on science standards in Kansas, see *PHYSICS TODAY*, October, page 73.) In introductory courses, we should step up our efforts to teach students the basics of the scientific method, including its strengths and weaknesses, the realms where it works well, and the realms where it does not. We can maintain a respect for religion and other “ways of knowing” while asserting that science is the best method we have for learning about how nature works. Although we may not display all the evidence for and against a theory like special relativity, we can tell students that it meets our criteria of internal consistency, predictive power, and experimental verification. We can also tell them that all the evidence they might want is in the science library in peer-reviewed journals.

Let’s contrast good science teaching with the propaganda of creationists. The so-called intelligent design movement offers no real scientific theories, no verifiable or falsifiable predictions, and no documentation in the scientific literature. One can quickly boil down its position to a simple argument based on authority. Whereas a good introductory science class can show students how scientific theories evolve when new evidence is uncovered, creationists have a history of reiterating the same tired arguments despite growing contradictory evidence. We can and should help our students see these differences between science and pseudoscience.

I don’t think Singham’s advice to students to “believe things only

when they make sense to you” is quite right. Has quantum mechanics ever really made sense to anyone? We should accept things in science when the experts appear to have good evidence and to have followed proper scientific procedures. The degree of acceptance should be based on the strength of the evidence and should never be absolute. If we can show our introductory science students the methods of scientific research and model for them the style of scientific argumentation, if we can help them to distinguish a real scientific argument from empty rhetoric and authoritarian propaganda, then we will have done an important part of our jobs as science educators.

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One gathers from Mano Singham that teaching science ought also to include teaching what science is not.

Physics is essentially an experimental science in which laws are arrived at by generalizing results obtained by experiments. Astronomy is an observational science, whereas cosmology and evolutionary theory are more akin to forensic science. Because cosmology and evolutionary theory deal with unique events and rely on deduction rather than induction, the search for truth is not as convincing or conclusive as it is in physics.

It is clear that detectors, governed by the laws of nature, can obtain all the data needed to do science. Such data are the sole input for scientific theories. Of course, the human mind is the creator of mathematics and develops the models to describe the systems determined by the physical data.

If nonhuman detectors cannot detect a thing, then it does not constitute scientific data nor is it the subject matter of science.

It is important to distinguish this type of data from the data gathered by humans when they are considered as “instruments” or “detectors.” The human “detector” takes in more than the purely physical; in particular, it “detects” intelligence or design in nature owing to the reasoning ability of the human mind. Making all this clear would have helped Doug realize that relativity is not a matter of belief but that what is required of a theory is that its predictions are consistent with experimental data. Such clarification might have led Jamal to realize that

cosmology is not a verbal scenario of the origin of what exists but rather a set of mathematical formulas that govern the dynamics of the universe.

Teachers ought to encourage students to express their skepticism of scientific concepts and theories. True learning occurs only when the learner, whether student or teacher, finds answers to his or her own doubts.

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SINGHAM REPLIES: A set of common assumptions underlies nearly all of the responses to my article.

▷ An empirical world (known as “nature”) exists that is external and objective.

▷ A clear distinction exists between experiment and theory.

▷ Experimental data serve as surrogates for nature.

▷ Theories can be evaluated by comparing their predictions with data.

This view of science is expressed in various ways by the letter writers. Gary Powell says that “science is a framework built around observations in nature.” W. C. Morrey adds that science uses “data and deductions,” and Moorad Alexanian tells us that “such data are the sole input for scientific theories,” and “physics is essentially an experimental science in which laws are arrived at by generalizing results obtained by experiments.” Hoi-Kwong Lo adds that all scientific theories must be subjected to the same test, with the evidence “weighed objectively.”

A hierarchy of knowledge structures is also postulated, with science rated higher than others because of its empirical basis and its method of operation. These two features make belief unnecessary because the data (nature) force theories on us (or at least constrain them). Hence we science teachers are not propagandizing but are justified in asking our students to accept the theories of science because, as Morrey puts it, “informed opinion is more valuable than uninformed, and experiment-based systems are more valuable than belief-based.” Phil Baringer points out that we can safely rely on “experts [who] appear to have good evidence and to have followed proper scientific procedures.” According to Pantazis Mouroulis, “Once proof has been achieved, belief becomes irrelevant.” Charles K. Sharnberger notes that science relies on “rational interpretation of empirical evidence . . .

as the pathway to truth.”

Among scientists, this formulation of scientific endeavor is widely held and seems so self-evident that people who disagree with it are perceived as irrational or oppositional. But is the distinction between the knowledge structures of science and nonscience really that clear-cut?

Clearly, science can make one particular claim: It works. Unlike any other form of knowledge, science provides a means of constructing machines and theories that are unequaled in their ability to predict and provide control. Our modern technological society is a monument to its success. Science also has created an intricate structure of knowledge to provide coherent and self-consistent explanations of a wide range of phenomena.

But while this success is incontrovertible, it may well obscure the subtleties of science's knowledge structure. Consequently, we may construct a model of scientific knowledge and evolution that makes science seem more different from other forms of knowledge than may actually be the case.

Philosophers and science historians such as Thomas Kuhn and Imre Lakatos¹ have wondered why science works so well. They have looked at its structure, its evolution, and the mechanisms by which scientific theories have progressed. Their analyses and conclusions will be unsettling to many scientists. They find that experiment and theory are not distinct categories, so that when one compares experimental data with theory, one is not really testing a theory by comparing it with nature. Instead, one is making a choice among competing theories, and no set of objective rules governs such a choice. The scientific community arrives at its theories in ways that are not entirely objective. No clear line of demarcation exists between experiment-based knowledge systems and belief-based ones. Some philosophers of science have even argued that the demarcation problem—that is, defining science so that it can be distinguished from religion—is inherently insoluble.

Scientists can ignore or summarily reject these conclusions by saying that we know that scientific knowledge is objectively obtained even if we cannot articulate exactly how we know this. But just as Mouroulis accords his “cosmology colleagues the same respect and skepticism that he expects from them,” we

should extend this courtesy to the philosophers and historians of science. Their works are scholarly, peer-reviewed, and critiqued by their colleagues. And these philosophers are admirers and supporters of science, not opponents. We at least owe it to them to study and understand their views. Otherwise we will be doing what we often criticize nonscientists for doing: rejecting counterintuitive ideas (such as wave-particle duality or time dilation) because they are “obviously” untrue.

One other aspect of this discussion puzzles me. The scientific community takes young-Earth creationists to task for holding irrational views but tends to ignore the views of mainstream religions, when the differences seem to be matters of degree and not of principle. Any theistic religion typically asserts the existence of at least one scientifically inexplicable supernatural event. Should scientists reject all such claims?

The committed naturalist would argue that we should, otherwise the entire framework of science will collapse. Science starts with the assumption that all natural phenomena are explainable by natural laws that can be discovered using the methods of science. No deviation from these laws is allowed. Miracles, which by definition are direct contradictions of the workings of natural laws, presumably have no place in this framework. Evolutionary geneticist Richard C. Lewontin² says it plainly: “We cannot live simultaneously in a world of natural causation and of miracles, for if one miracle can occur, there is no limit.” His point is well taken. If the scientific community concedes even one miraculous event, then how can it credibly contest the young-Earth creationist view that the world (and all its fossilized relics) was created in one instant just 6000 years ago? So if we reject creationist views on this basis, should we also reject any supernatural claim from *any* religion?

These are thorny and nontrivial issues, which need the kind of extended discussion that I have provided elsewhere.³ But for the present, I can only echo letter writer Philip E. Kaldon, who sums it up beautifully:

It is easy to say that we physics teachers do not teach “belief” because we are teaching science. It is not so clear-cut to the students—and sometimes those of us teaching. And at the end of the day... I am

grateful to those who have spent the time to think about what they are being asked to think about, no matter their personal conclusions.

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Background Highlights in X-Ray Imaging

In connection with the article entitled “Phase-Sensitive X-Ray Imaging” in the July issue of PHYSICS TODAY (page 23), I would like to add a little more background to two aspects of the topics covered. First, in the context of crystal-based methods of phase-sensitive imaging, the early work of Eckhart Forster, Konrad Goetz, and Peter Zaumseil¹ is worthy of mention because it was apparently the first example of a deliberate double-crystal approach to phase-contrast imaging (which they called “Schlieren topography”), and precedes the phase-dispersion introscopy (PDI), or diffraction-enhanced imaging (DEI), approach referred to in the article. The work of Forster, Goetz, and Zaumseil described x-ray investigations of laser fusion targets by a double-crystal method and contained a wave-optical explanation of the observations. I believe the existence of this paper only became known to the authors of papers cited in the article after their papers had been published.

Second, regarding phase-contrast radiography, phase retrieval from intensity data is currently a lively area of research, providing a non-interferometric means for quantitative phase determination that bypasses the usual 2π ambiguity encountered in the interferometric approach. The noninterferometric approach relies on the mathematical