relativity of inertial frames and atomism. Those were not consensus views at the time, so to pursue them he had to risk his career; and for that he needed a strong dose of intellectual independence and courage. Had he been as talented and intuitive but less independent, he might have been able to contribute to the development of existing ideas, following the great physicists of the time such as Max Planck and Hendrik Lorentz. But then he might not be remembered today and physics would be poorer for it.

On the other hand, Planck and Lorentz are to be admired because even if they were on the wrong side of the key issues, they recognized the importance of Einstein's work and encouraged and supported his career. They cared more for science than for their own legacies and research programs, so they put their support behind the young rebel whose work, it turned out, ended their own research programs. This shows that the contributions of Einstein, Lorentz, and Planck were due as much to their characters as to their cognitive and computational skills.

This illustrates why I disagree with Lev Landau's simplistic but common notion, raised by Asoke Mitra, that physicists can be ranked in a one-dimensional hierarchy. My view, supported by everything I have experienced in science, is that this status game is both wrong and destructive to the progress of science because the progress of physics requires a diversity of talents, approaches, and styles.

Let me offer a better metaphor than the schoolyard for thinking about how physicists differ—a metaphor suggested to me by Eric Weinstein. We can think of physicists as mountain climbers, with the new theory we are looking for as a high peak in the distance. Unfortunately, the landscape is foggy and we climbers can only see far enough to tell which direction is up from where we are. To discover the peak requires different kinds of climbers. At some points we need good technical climbers. Put them on any slope and they will make it quickly to the nearest hilltop. Many of them also like to climb in groups, so that they have an audience to whom they can show off their skills. The problem is that once they get to the top, they get stuck. To find other hills, which may lead to the real summit, we need climbers whose styles are more adventurous and individualistic, who prefer to leave the crowded lower peaks and strike off across perilous ridges. We also need a few loners who prefer to spend their time fording rivers and crossing valleys, discovering new mountains.

Einstein may have been the best valley crosser we've ever had; almost everything he did either sparked a revolution or was an attempt to do so. But contemporaries reported that many people were better at the technicalities. Landau worked in a different period, when the revolution was considered over and what was admired was great speed and technical climbing skills, based on established frameworks. Could Einstein have competed with Landau at what Landau did best? The evidence is that Einstein was not even good at working out the implications of his own theory of general relativity; most of the important exact solutions, which require only elementary methods from differential equations to discover, were quickly found by others.

So Mitra misunderstands my proposal. It is not to mass-produce prodigies. It is to find and support more valley crossers, who have trouble making good careers in an atmosphere that promotes great technical climbing skills as indicative of a good scientist. This does not require a big change in policy, as not many people qualify as valley crossers. What is needed is only that some agencies and foundations learn to act as venture capitalists, to give those who take the big risks needed to solve the big problems a chance to do their work.

Lee Smolin
Perimeter Institute for Theoretical Physics
Waterloo, Ontario

Teaching physics mysteries versus pseudoscience

Physicists properly join today's arguments involving the teaching of Darwinian evolution. There is, however, a social issue closer to the responsibility of physicists: Quantum physics is increasingly invoked to promote pseudoscience.

Such promotions may start with correct statements of the intriguing implications of quantum mechanics, move to legitimate hyperbole, and then go off into complete hype. Take a recent "international hit" movie as our case in point. It's strangely titled *What tHe #$*! Do wΣ (k)πow!? (What the Bleep Do We Know!?)* An article in *Time* magazine described it as "an odd hybrid of science documentary and spiritual revelation featuring a Greek chorus of PhDs and mystics talking about quantum physics."[1]

Early on, the movie illustrates the uncertainty principle with a bouncing basketball being in several places at once. There's nothing wrong with that. It's recognized as pedagogical exaggeration. But the movie gradually moves to quantum "insights" that lead a woman to toss away her antidepressant medication, to the quantum channeling of Ramtha, the 35 000-year-old Atlantis god, and on to even greater nonsense.

Most laypeople cannot tell where the quantum physics ends and the quantum nonsense begins, and many are susceptible to being misguided. According to polls, well over half of the people in the US and England have significant belief in the reality of supernatural phenomena. Robert Park states the problem well. "Many people . . . seek a certainty that science cannot offer. For these people the unchanging dictates of ancient religious beliefs, or the absolute assurances of zealots, have a more powerful appeal. Paradoxically, however, their yearning for certainty is often mixed with a respect for science. They long to be told that modern science validates the teachings of some ancient scripture or New Age guru. The purveyors of pseudoscience have been quick to exploit their ambivalence."[2] We should not underestimate how persuasively physics can be invoked to buttress mystical notions. We physicists bear some responsibility for the way our discipline is exploited.

The human implications of quantum mechanics that fuel popular discussion arise in the measurement problem and in entanglement. Those terms are at least how we refer to the topics in a physics class, where we rarely go much beyond their mathematical formulation. Elsewhere, the same issues are legitimately discussed more broadly in terms of the nature of reality, universal connectedness, and consciousness. But we don't distract physics students with excursions into issues that extend embarrassingly beyond the boundaries we define for our discipline. Science historian Jed Buchwald notes that physicists "have long had a special loathing for admitting questions with the slightest emotional content into their professional work."[3] Accordingly, unlike the biology student able to defend evolution against intelligent design, a physics student may be unable to convincingly confront unjustified extrapolations of quantum mechanics.

It's not the student's fault. For the most part, in our teaching of quantum mechanics we tacitly deny the mysteries physics has encountered. We hardly mention Niels Bohr's grappling with the encounter between physics and the observer and John von Neumann's demonstration that the encounter is, in principle, inevitable. We largely avoid the still-unresolved issues raised by Albert Einstein, Erwin Schrödinger, Eugene Wigner, David Bohm, and John Bell. Outside the classroom, physicists increasingly address these issues and often go beyond the purely physical. Consciousness, for example, comes up explicitly in almost all of today's proliferating interpretations of quantum mechanics, if only to show why physics need not deal with it. The many-worlds interpretation, for example, is also referred to as the many-minds interpretation, and a major treatment of decoherence concludes that an ultimate understanding of the implications of quantum mechanics would involve a model of consciousness.

The Copenhagen interpretation is, of course, all we need to describe the world for all practical purposes. And for a physics class, practical purposes are all that generally matter. But a physics student confronting someone inclined to take the implications of quantum mechanics to unjustified places will find Copenhagen's for-all-practical-purposes treatment an ineffective argument.

We are unable to present students with a "reasonable" picture for what's going on in the physical world, one that goes beyond merely practical purposes. But a lecture or two can succinctly expose the mysteries physics has encountered, reveal the limits of our understanding, and identify as speculation whatever goes beyond those limits. Such a presentation is possible even in a physics class for non-science majors and would enable students to effectively confront the quantum nonsense. Physics's encounter with the observer and consciousness can be embarrassing, but that's no reason for avoidance. The analogy with sex education comes to mind.

References

1. D. Cray, *Time*, 16 August 2004, p. 22.
2. R. Park, *Voodoo Science: The Road from Foolishness to Fraud*, Oxford U. Press, New York (2000), p. 39.
3. J. Glanz, *New York Times*, 21 May 2002, p. F4.

Fred Kuttner
(fkuttner@ucsc.edu)
Bruce Rosenblum
(brucero@ucsc.edu)
University of California, Santa Cruz

Averaging operators in turbulence

Although Gregory Falkovich and Katepalli Sreenivasan review important lessons from hydrodynamic turbulence (PHYSICS TODAY, April 2006, page 43), we think the field has left us a legacy of Reynolds averaging whose worth needs to be reevaluated. The foremost reason why turbulent flows "confound any simple attempts to understand them" is that, as the authors point out, "questions about turbulent flows can be posed and answered *only* in terms of statistical averages" [emphasis ours]. Falkovich and Sreenivasan represent this averaging with angle brackets, $\langle \ldots \rangle$, on page 44 but gloss over the fundamental importance of averaging operators in turbulence; they say only that angle brackets denote "a suitable average."

Experimentalists have inherited Reynolds averaging for obtaining estimates of $\langle \ldots \rangle$, but such averaging is appropriate only when the turbulence is in steady state. The atmosphere, for example, is a turbulent fluid that is rarely in steady state.

Early work by Sreenivasan and coworkers[1] and by others[2,3] revealed that Reynolds averaging of turbulence time series leads to lagged autocorrelation functions whose net area under the curve is zero. That is, they imply zero integral scale. Our recent work[4] has built on that result to conclude that block averaging, the recommended modern version of Reynolds averaging[5] formulated to analyze turbulence time series recorded over long periods, generates turbulence statistics whose time evolution is incompatible with the Navier–Stokes equation. A comparable result emerges for the conservation equation for passive scalars described on page 47 of the PHYSICS TODAY article. The authors say those "who study turbulence believe that all its important properties are contained" in those equations. Although we concur with that statement, the newly found incompatibility[4] is unacceptable.

Reynolds averages evidently have subtle features that conflict with fundamental physical laws. These features are a consequence of using an averaging method appropriate for data that are stationary and independent to analyze data that are stationary and correlated. Therefore, the links "between turbulence, critical phenomena, and other problems of condensed matter physics and field theory" that Falkovich and Sreenivasan anticipate from future re-