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.

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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 research may remain hidden until more robust methods for assessing the time-specific as well as time-invariant average properties of turbulence are formulated. Standard Reynolds averaging and its modern refinements, unfortunately, are not reliable for deducing the statistical properties of turbulence.

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Falkovich and Sreenivasan reply: Our review was devoted to fundamental physical properties of turbulence. These properties manifest themselves most clearly in instances that are statistically steady and homogeneous. We interpret the letter writers' concern to mean that one has to be careful, in general circumstances, about the choice of the averaging procedure. Indeed, one needs to exercise care in defining averages for nonstationary processes or those with insufficient data. However, that fact does not invalidate the Navier–Stokes equations or the advection–diffusion equation.

One possible explanation for the zero values of the inferred integral scale is the inadvertent filtering out of the very lowest frequencies from a measured turbulent signal. This was an attribute of much of the instrumentation used some 30 years earlier, before the digital revolution became commonplace.

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