that one is simply having difficulty with the starting assertion.

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Authors Singh, Belloni, and Christian demonstrate how visualizations can help students learn some of the most difficult and counterintuitive principles in the physics curriculum. But as two surveys have shown, there are broader roles for computation in that curriculum that ought to be, but currently are generally not being, used to help prepare physics students for their likely work environments.

An August 2002 survey by the American Institute of Physics (available at http://aip.org/statistics/trends/reports/bachplus5.pdf) looked at physics bachelor graduates in the nonacademic workplace at least five years beyond their graduation. The results revealed a significant gap between their computational preparation as undergraduates and the computational demands of their work. The AIP survey does not detail these demands, but from my own experiences in engineering research and development environments, I've found that they include constructing and validating numerical models as well as interpreting results from running those models. In short, holders of physics bachelor's degrees must be able to think about their physics in computational terms.

The other survey, completed by Robert Fuller from the University of Nebraska–Lincoln, provides some answers to how much computation is included in today's physics curricula of colleges and universities nationwide. The answers indicate wide variability in the degree of computation amid a widespread agreement by faculty on the importance of integrating computation into their courses. Fuller concludes that physics departments in the US generally acknowledge the need for more computation in their curricula, but most are not meeting the need in a systematic way. This gap—between acknowledged need and community response—is consistent with AIP's survey findings. The September/October 2006 issue of *Computing in Science and Engineering* gives Fuller's report and provides some examples of possible ways to close the gap. They include the "lone wolf" who is the sole interested person in the department; the "persuasive pioneer," implementer of a full computational physics undergraduate major; and a range of cases in between.

I believe the physics community needs to reconceive the canon of the undergraduate physics curriculum to include a significant role for computation. Whether or not they learn their physics principles with computation embedded, students will need to put their knowledge to productive use in their work. Today that usually means through computation.

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In their article "Improving Students' Understanding of Quantum Mechanics," the authors present the following survey question: "By definition, the Hamiltonian acting on any allowed state of the system Ψ will give the same state back, i.e., $H\Psi = E\Psi$. . . . Explain why you agree or disagree." This wording appears to be ambiguous, since an "allowed state of the system" seems to connote an eigenstate. Perhaps better wording would be "the Hamiltonian acting on any wavefunction Ψ," or even better, "acting on a wavefunction Ψ in Hilbert space," rather than referring to the state as "allowed."

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I have found the recent articles on improving physics education very helpful—please keep them coming! Although I am a physics undergraduate looking toward a future in research, such articles have influenced me at least as much as your articles on physics innovations.

I was very lucky to have an outstanding advanced placement physics teacher. His explanations and guidance were simple yet effective, and he led the class through his entire thought process when working out examples. Although most of the students were not going into physics or engineering, almost all were able to understand the material. His brilliant instruction was one of the factors that made me choose to be a physics major.

On the other hand, I am privy to the horror stories of my friends taking introductory physics for science majors under other instructors. The range of experiences, from stunning to devastating, have encouraged me to focus on teaching as well as research. Please, keep the physics education articles coming. At a time when our country is facing a lack of science education, how physics is taught may be one of the most important areas to study.

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Singh, Belloni, and Christian reply: We appreciate the number and quality of the responses to our article. They indicate a strong interest, which we share, in the teaching of upper-level courses such as quantum mechanics. Our article focused on the concept of time evolution to illustrate a variety of difficulties students face; we barely scratched the surface of the breadth and depth of teaching and learning issues in a standard quantum mechanics course.

We value highly the perspectives on fundamental issues from Robert Griffiths and Travis Norsen, who raised similar concerns from different viewpoints. Foundational issues in quantum mechanics are not emphasized in most undergraduate or graduate quantum mechanics curricula. Griffiths has argued that the lack of proper grounding in foundational issues is the source of many student misconceptions in quantum mechanics. The consistent histories approach[1] or Bohm's interpretation[2] may be conceptually "cleaner," but our research has shown that many of the difficulties—for example, the confusion between the time-independent and time-dependent Schrödinger equation—are not foundational but conceptual.

As a practical matter, non-Copenhagen interpretations are not widely incorporated in quantum mechanics textbooks. We have argued that there are ways to improve student understanding within the current framework—surely, these general methods will work if and when the physics community has collectively adopted new ways of thinking about quantum mechanics.

Physics education research is well-established now, and a controlled study involving two quantum mechanics classes taught by the same instructor might be worthwhile. One class could use the standard Copenhagen interpretation while the other uses the consistent histories approach. An important question, then, is this: If both classes cover approximately the same amount of material and students in both classes are given the surveys we have developed, do students in one class significantly outperform those in the other? In addition to the written surveys, a subset of students from both classes could be interviewed to further ascertain their level of understanding. If students using the consistent histories approach significantly outperform those learning the standard Copenhagen interpretation, it may be worthwhile to develop interactive tutorials similar to those discussed in the article but using the consistent histories approach.

In response to Travis Norsen, we note that we agree with Alan Van Heuvelen, whom Norsen cites, and our approach is consistent with his advice.[3] However, intuition and foundational issues are not exactly the same things. Although a deep understanding of foundational issues may improve intuition, we can help our students develop qualitative, conceptual understanding of many aspects of quantum theory without first having to clarify every foundational issue. Our research suggests that the nature of physical intuition is not well understood, though intuition is important.[4]

As Philip Shemella has suggested, we have used other wordings for the question of interest, including the wording he recommends. Our findings are unchanged. During interviews, the interviewer has often rephrased the question when a student was unable to answer correctly. The responses were qualitatively unchanged.

As Griffiths, Norsen, and Walter Harrison imply, the use of simulations and results from physics education research to address functional issues is just a single prong in what should be a multi-pronged approach to the teaching of quantum mechanics. We agree that addressing foundational issues is just as important.

In addition to the approach taken in textbooks by Griffiths and Harrison, Richard Robinett's quantum text[5] relates pedagogical quantum models to modern experimental realizations of these systems and emphasizes connections to classical mechanics.

We agree with Norman Chonacky that a discussion of the broader role of computation in the physics curriculum is needed. We encourage interested readers to attend the American Association of Physics Teachers topical conference Computational Physics for Upper Level Courses, to be held in July 2007 (see http://www.opensourcephysics.org/CPC/index.html). Its purpose is to identify problems in which computation helps students understand key physics concepts.

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Uncertainty over weakening circulation

Barbara Goss Levi's Search and Discovery story (PHYSICS TODAY, April 2006, page 26) discusses evidence of weakening ocean circulation and its possible connection to global warming. The Atlantic Ocean circulation across 25° N latitude has been used as a benchmark for characterizing the mass and heat transport from the tropics to the northern latitudes. The upper portion of this transport includes the Gulf Stream, which is at least partially responsible for a moderate climate in Europe. A weakening of the Atlantic meridional overturning circulation and of the Gulf Stream might have the unpleasant consequence of cooling Europe's climate.

The PHYSICS TODAY piece is based on analysis of work by Harry Bryden, Hannah Longworth, and Stuart Cunningham,[1] which concluded that the Atlantic meridional overturning circulation slowed by about 30% between 1957 and 2004. Their work inspired speculations that the anthropogenic increase in carbon dioxide may be responsible for the weakening of heat transport from the tropics, and that such an effect has now been detected.

The conclusion that the Atlantic meridional overturning circulation has decreased by 30% does not follow from the data presented by Bryden and coauthors, but is based on an incorrect treatment of measurement errors.

According to Bryden and coauthors, the 1957 transport in a layer shallower than 1000 m was 22.9 ± 6 Sverdrups (1 Sv = 10^6 m^3/s) compared with the transport of 14.8 ± 6 Sv in 2004. The ± 6 Sv represents an uncorrelated error of each measurement. Bryden subtracts the two quantities and presents the results as 8.1 ± 6 Sv (instead of 8.1 ± 12 Sv or ± 8.5 Sv, depending on the character of errors), which is an incorrect result. It is a mystery how such an error was missed by Levi and by the editors and reviewers of the original paper. The observed change of 8.1 Sv is well within the uncertainty of the measurement. The correct conclusion from the data presented in Bryden's paper should have been that no statistically significant change in Atlantic meridional overturning circulation at 25° N between 1957 and 2004 has been detected. Such a conclusion is in agreement with the earlier analysis of essentially the same data (between 1957 and 1999) by Alexandre Ganachaud and Carl Wunsch.[2]

Research also failed to detect any slowing,[3,4] and one of the relevant papers[4] concludes that "there is no sign of any Meridional Overturning Circulation slowdown trend over the past decade, contrary to some recent suggestions."[1]

In defense of Bryden and his coauthors, I must share a comment from a personal communication I had with Bryden shortly after his *Nature* paper was published. Bryden's paper as submitted for publication to *Nature* included a question mark at the end of the title, suggesting only a possibility that the circulation might be slowing down. On the editor's insistence, the question mark was removed, and the title was changed into a positive statement that caused a considerable stir.

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Postscript on Chandra and Eddington

The letters from Arthur Miller and Kameshwar Wali (PHYSICS TODAY,