# The future of physics education research: Intellectual challenges and practical concerns

During the World Year of Physics, much effort is being made to celebrate the unprecedented advances in our understanding of the physical world made during the past century. However, we have not yet seen comparable advances in our understanding of student learning of our discipline. One possible explanation is that learning is inherently more complex than most physical processes. Although this explanation is plausible, we have not made similar systematic efforts to understand student learning. The enormous effort expended by many physics instructors over the past century was not harnessed in a way that made cumulative progress likely. As Lillian McDermott has observed, ‘‘Unless we are willing to apply the same rigorous standards of scholarship to issues related to learning and teaching that we regularly apply in more traditional research, the present situation in physics education is unlikely to change.’’1

In the past few decades, an increasing number of physicists have taken up this challenge by applying methods of research based on those that have been employed successfully in investigations of the physical world. This endeavor is broadly known as ‘‘physics education research’’ ~PER**!**. Systematic studies of student learning have revealed a wide gap between the objectives of most physics instructors engaged in traditional forms of instruction and the actual level of conceptual understanding attained by most of their students.2

But PER has gone beyond documenting shortcomings in student learning and traditional instruction. Researchers have developed instructional materials and methods that have been subjected to repeated testing, evaluation, and redesign. Numerous reports have documented significant and reproducible learning gains from the use of these materials and methods in courses ranging from large-enrollment classes at major public universities to small classes in two-year colleges and high schools.1–3 Still, there remain inadequacies in even the most recent instructional approaches and many unanswered questions. In this Guest Editorial we will identify some of the current and emerging research directions that we consider promising. We also argue for the importance of doing research on the learning and teaching of physics in physics departments. We do not mean to suggest that PER should not be conducted in schools of education, but, as we argue later, we do not believe that the field is viable without a critical mass of faculty in physics departments. Finally, we identify some practical and political challenges and propose some steps that could be taken to help ensure the stability, growth, and productivity of PER.

*Current and future research directions*. We first briefly mention some of the research directions that have potential for deepening our understanding of how students learn physics. This understanding should lead to more effective instructional tools, techniques, and materials. We highlight those directions that address intellectual issues that are specific, but not necessarily unique, to the subject matter and reasoning patterns of physics. Therefore we omit important work on investigating gender-equity issues, for example. Moreover, we focus on the college and university level, although some issues we mention have implications for K-12 instruction. We do not wish to neglect the large and vigorous PER community outside the U.S. However, although many fundamental issues of student learning are largely invariant across cultures, the diversity of approaches to education and, consequently, of research goals is too broad to be addressed satisfactorily here.

Most early PER work focused on student ability to apply the concepts covered in typical introductory university physics courses. The results of these studies have proven invaluable in guiding improvements in instruction. The breadth of topics covered, their importance as a foundation for future study, and the many students involved ensure that the introductory course will continue to be a major emphasis for the foreseeable future. Current research efforts range from extensions of earlier studies of student ability to interpret and apply kinematical concepts4 to investigations of student understanding of basic electromagnetism and modern physics.

In recent years, there has been an increasing focus on student learning in upper-level courses such as quantum mechanics,5 thermal physics,6 relativity,7 and advanced mechanics.8 This research should lead to learning gains for physics majors similar to those found for research-based instruction at the introductory level.

We also expect to see a greater emphasis on tracing students' intellectual development as they progress through the undergraduate curriculum, both in physics and in related disciplines such as engineering. Although a few relevant studies have been conducted9 ~the results of which are consistent!, most are unpublished. It is important that these studies be conducted and the results be widely disseminated. These investigations should lead to the development of strategies that help students apply the knowledge and skills developed in their physics courses to their subsequent studies or nonacademic pursuits.

Helping students to approach novel problems in a systematic fashion is a major goal of physics instruction. It also is one of the most difficult goals to achieve, although significant success has been reported.10 However, much remains unknown. Efforts to understand the interrelationships among conceptual knowledge, mathematical skills, and logical reasoning ability should significantly enhance our progress toward helping students become better problem solvers.11

The rapid proliferation of computer-based technologies represents both an opportunity and a challenge. Technically sophisticated simulations, animations, and multimedia representations of physics concepts are being developed and implemented by many instructors and curriculum designers, but research into the effectiveness of these technologies lags far behind development.12 It will be a major challenge to assess the effects of these technologies on student understanding of abstract physics concepts, the nature of scientific models, and the relation of both to the natural world. Such research is crucial for informing the implementation and further development of computer-based instructional tools.

In recent years, students' beliefs about the nature of knowledge in physics and how it is acquired have become a major focus of interest.13 There is reason to suspect that such epistemological beliefs can influence students' learning of physics and their development of more generalized reasoning