Chemical Education and Physics Education: Facing Joint Challenges and Practical Concerns*

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Recently there have been discussions between chemists and physicists directed at organizing a series of joint meetings on learning and teaching, with chemical educators presenting their work at conferences of the American Association of Physics Teachers, and physicists reciprocating at ACS meetings. During these discussions we have learned of the large common ground we share in our work, particularly in the area of discipline-based education research at colleges and universities. Our common experiences and interests suggest that much may be gained by further joint discussions and activities.

For over a hundred years, colleges and universities in the United States have carried out intensive instruction in chemistry, physics, and other technical subjects. Systematic research in these fields has expanded tremendously during this period as well. However, it is a relatively recent phenomenon that the process of learning and teaching these subjects at the college level has been regarded as a potentially fruitful area of research in its own right. As readers of this Newsletter are probably aware, chemical education research (CER) has become a research specialty pursued at about two dozen research-oriented chemistry departments in the U.S. More than half of these departments currently award the Ph.D. degree for dissertation research in chemical education. Similarly, there has been explosive growth in the field of physics education research (PER) during the past fifteen years. There are now over 80 physics departments at U.S. colleges and universities employing at least one faculty member pursuing research on the teaching and learning of physics. About 35 of these departments are research-intensive Ph.D.-granting departments, and approximately 15 such departments have already awarded or plan to award a Ph.D. degree in physics for research in physics education.

The development of PER reflects the growing realization by many physicists that in contrast to the efforts that have led to remarkable advances in science and technology, the enormous effort expended by many physics instructors over the past century was not harnessed in a way that made cumulative progress in education likely. Instead, innumerable individual instructors discovered and re-discovered inadequacies in

popular teaching methods and instructional materials, and developed their own ways to address these problems based on personal experience through trial-and-error methods. However, as one leading physics education researcher 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." As is occurring in chemistry, 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. Systematic studies of student learning have been carried out that incorporate careful collection and analysis of data based on deep probes of students' reasoning. Many such studies have been replicated with widely diverse institutions, instructors, and student populations. These investigations 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. Physics education researchers have developed instructional materials and methods that have been subjected to repeated testing, evaluation, and re-design. 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 twoyear colleges and high schools.² In what follows, we will identify some of the current and emerging research directions in PER that we consider promising. We also identify some practical and political challenges to the growth of PER, and we argue that these are virtually identical to challenges facing the CER community. With that in mind, we will propose some common steps that could be taken to help ensure the stability, growth, and productivity of both CER and PER.

Current and emerging research directions in PER

Most early PER work focused on student ability to apply the concepts covered in typical introductory university physics

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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 ensures that research in the introductory course will continue to be a major emphasis for the foreseeable future. However, in recent years, there has been an increasing focus on student learning in upper-level courses such as quantum mechanics, thermal physics, relativity, and advanced mechanics. This research should lead to learning gains for physics majors similar to those found for research-based instruction at the introductory level.

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 a few approaches have had significant success.³ 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.

In both physics and chemistry, the rapid proliferation of computer-based technologies represents both an opportunity and a challenge. Technically sophisticated simulations, animations, and multimedia representations of physics and chemistry concepts are being developed and implemented by many instructors and curriculum designers, but research into the effectiveness of these technologies lags far behind development. It will be a major challenge to assess the effects of these technologies on student understanding of abstract 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.⁴ There is reason to suspect that such epistemological beliefs can influence students' learning of physics and their development of more generalized reasoning skills. Future directions will include efforts to understand these relationships and to incorporate the results in practical instructional strategies and materials.

The empirical investigations of student learning in PER are usually carried out within a framework of ideas regarding the underlying causes of common student errors and the nature of the learning process. The refinement of such frameworks, with the ultimate goal of elucidating a few fundamental principles from which broad explanatory if not predictive power can be derived, is the focus of some physics education researchers.⁵

Necessity for Discipline-Based Education Research

Research on education in general, and on science teaching in particular, has been carried out for nearly a century. However, the impact of this research on undergraduate science instruction is small compared to the influence of education research

originating from within the disciplines. The explanation is simple: education research conducted by scientists in science departments is more credible, more accessible, and more relevant to college and university science faculty than that conducted in colleges of education or departments of psychology, although the conclusions are typically consistent. Moreover, we note that "the research-based development of tools and processes for use by practitioners" —long a primary goal of most CER and PER workers—is a relative rarity in traditional educational research. Thus while we view increased collaboration with cognitive psychologists, education researchers and neuroscientists to be of potential benefit, we believe that for CER and PER to continue to be influential, it is important for researchers to maintain close ties with the traditional science community.

Practical and Political Issues Facing the PER Community
Although the rapid growth of PER suggests that the field is

Although the rapid growth of PER suggests that the field is thriving, there are several serious hurdles that must be overcome for it to become a viable subfield of physics. The fact that a significant fraction of PER faculty are tenure-track assistant professors is a concern. There is a tendency in some departments for PER faculty to be viewed as resource people, whose major responsibility is to provide local support for instruction rather than to conduct scholarly research. We believe that faculty in PER and CER need to have the same opportunities for advancement based on their scholarly work as those in other areas of research. This will ensure that the quality of physics and chemistry education research remains high and that talented people continue to enter these fields.

Another area of concern is the availability of funding. The current level of activity in CER and PER requires a stable source of support to be sustained. Such work is now funded primarily by the National Science Foundation, but in general the research aspect of funded projects is secondary to curriculum development, teacher education courses and workshops, and other programs of interest to the various funding agencies. There is no source of funding for chemistry or physics education research per se. The traditional models of chemistry and physics research funding, such as the renewable threeyear grants available to individual researchers by the NSF Divisions of Physics and Chemistry, are virtually unknown in PER and CER. The lack of a funding base within NSF for discipline-based education research, despite its documented successes, is a problem not just for chemistry and physics but also for the other sciences and engineering. We believe that chemists and physicists at NSF could be effective in promoting the establishment of mechanisms for funding disciplinebased education research within the Foundation. The NSF Directorate for Mathematical and Physical Sciences (MPS) has recently taken tentative steps to support a small number of PER projects. If this initiative leads to increased and sustained support, it could have a significant impact.

The growing number of faculty positions indicates that CER and PER are increasingly viewed as legitimate fields for scholarly research by chemists and physicists in college and

university science departments. However, many still question whether effective teaching, long considered a skill or even an art, is amenable to scientific study. The large number of variables involved in student learning in the classroom is usually assumed to render the scientific study of science education more difficult than most investigations of the physical world. We do not dispute this assumption, but we note that research in traditional areas of science also is characterized by difficulties in identifying and controlling variables and by the necessity of making and assessing assumptions, approximations, and models. Chemists and physicists deal with these issues on a regular basis. Resolution comes only through the continual testing of models and assumptions by many research groups over the long term. Therefore, it is reasonable to expect that respectful consideration by the broader community of scientists will be given to well executed CER and PER investigations, just as would be given to such investigations in other areas of science. After all, CER and PER both rest on a simple, fundamental premise that should have wide credibility among research scientists, that is: systematic research is an appropriate way to learn as much as possible about what students are learning and to guide improvements in instruction where indicated.

Conclusion

By promoting joint discussions and collaborative projects, workers in CER and PER have the opportunity to enhance significantly the impact of their work on the traditional chemistry and physics communities. Some such collaborations have already resulted in joint NSF-supported projects and joint publications in science education journals. We believe that extension of such collaborations on a national scale would be an important development in furthering discipline-based science education research at the undergraduate level.

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