Foundational Material II: Research on Physics Teacher Education

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Overview

Relatively few published research studies have addressed the impacts of U.S. physics teacher education programs. However, several recent investigations have probed the outcomes of programs in which there is a strong focus on physics-specific pedagogy using research-validated instructional methods of the type recommended in this Report.[1]

An unusual and revealing investigation was commissioned by the National Science Foundation (NSF) and carried out by the TIMSS International Study Center at Boston College.[2] In this study, the TIMSS twelfth-grade physics test was administered to a random sample of twelfth-grade students taught by teachers who had participated in NSF-sponsored teacher enhancement and materials development programs. These NSF-sponsored programs included several that were based on research in physics education and that used instructional methods described and endorsed in this report. The study revealed that students taught by teachers who had participated in the NSF-sponsored programs significantly outperformed other U.S. high school physics students who had taken the same test.[3]

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A number of other studies reported in peer-reviewed journals and proceedings have examined outcomes from individual university-based teacher education programs. In the remainder of this section we will review and briefly summarize several of these studies; detailed reports may be found in the cited references.

Research on Programs for Prospective and Practicing Teachers

Pre-service teachers in the University of Washington's *Physics by Inquiry* program taught lessons on light in a ninth-grade classroom using materials and methods they had themselves recently learned. Their ninth-grade students had much higher scores (45%) on post-instruction diagnostic tests than did undergraduate university physics students in traditional physics courses taking the same tests (20%).[4] A summer program at California State University San Marcos that also used the research-based *Physics by Inquiry* curriculum reported strong learning gains among in-service middle school and high school physics teachers, as measured by improvements in performance on physics concept tests. Delayed tests administered six to eight months after instruction found good to excellent retention of the learning gains. [5]

Students of teachers who participate in Arizona State University's "Modeling Instruction" in-service program have consistently shown much better performance on the "Force Concept Inventory" mechanics diagnostic test than students of teachers who had not been through that or any comparable program.[6] Other evidence shows that both pre-service and in-service teachers who participate in workshops using the Modeling method demonstrate greater gains on physics concept tests than do students enrolled in comparable courses that use only standard textbooks and instructional methods.[7]

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1. This section draws on material from David E. Meltzer, "Research on the education of physics teachers," *in Physics Teacher Education: Research, Curriculum, and Practice*, edited by David E. Meltzer and Peter S. Shaffer (American Physical Society, College Park, MD, 2011), pp. 3-14.
2. TIMSS (Trends in International Mathematics and Science Study) is an international study of students' mathematics and science achievement.
3. TIMSS International Study Center, *TIMSS Physics Achievement Comparison Study* (TIMSS International Study Center, Chestnut Hill, MA, 2000). Available at: http://modeling.asu.edu/Evaluations/TIMSS_NSFphysicsStudy99.pdf.
4. Lillian C. McDermott, Paula R. L. Heron, Peter S. Shaffer, and MacKenzie R. Stetzer, "Improving the preparation of K-12 teachers through physics education research," *American Journal of Physics* **74**, 763-767 (2006).
5. Graham E. Oberem and Paul G. Jasien, "Measuring the effectiveness of an inquiry-oriented summer physics course for in-service teachers," *Journal of Physics Teacher Education Online* **2**(2), 17-23 (2004).
6. An early report is in David Hestenes, Malcolm Wells, and Gregg Swackhamer, "Force Concept Inventory," *The Physics Teacher* **30**, 141-158 (1992), and a follow-up report is in Malcolm Wells, David Hestenes, and Gregg Swackhamer, "A modeling method for high school physics instruction," *American Journal of Physics* **63**, 606-619 (1995). The data are reviewed within a larger perspective by Richard R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *American Journal of Physics* **66**, 64-74 (1998). More recent data are discussed in an evaluation report prepared for NSF, available at: http://modeling.asu.edu/R&E/ModelingWorkshopFindings.pdf.
7. Meltzer, "Research on the education of physics teachers," Section IVC.ii.

The Rutgers University program for pre-service physics teacher education is based on a sequence of courses on physics-specific pedagogy, founded on physics education research. Evaluations of program participants show that their knowledge of both physics concepts and science processes (such as experiment design) improve dramatically over the course of the program, with final scores showing high proficiency. These objective measures were consistent with evaluations by the students' mentor teachers and science supervisors.[8]

Extensive studies of students who participate in the University of Colorado's "Learning Assistant" pre-service program have documented dramatic learning gains not only in introductory-level physics courses but in advanced-level courses as well.[9] Follow-up observations and interviews with former participants in the program indicate that teaching practices of first-year secondary science teachers who had been in the program are more closely aligned with national science teaching standards than practices of comparable first-year teachers who had not been part of the program.[10]

An in-service program at the University of Colorado engages physics and physical-science teachers in curriculum planning, and in research on their own classroom teaching practices. Together they review and reflect on their work from the standpoint of findings in the science education literature. A variety of written and video data indicate clear progress by the participating teachers toward teaching practices and ideas that are consistent with recommendations in the science education literature.[11]

The Constructing Physics Understanding (CPU) project at San Diego State University included summer and academic-year workshops targeted at in-service high school teachers. These workshops included inquiry-based investigative activities developed through physics education research. High school students taught by workshop participants recorded higher scores on physics concept exams than students taught the same concepts by a very comparable group of teachers who had not taken the CPU workshops. The highest scores were recorded by students of teachers who had previous CPU experience and who had helped lead the workshops.[12]

An Israeli program utilized methods closely analogous to those employed by U.S. researchers. This program guided in-service physics teachers to develop, and use in their classrooms, curricular materials and instructional methods based on physics education research. These teachers' students performed better on tests of electromagnetism concepts than did students at the same schools who used standard instructional materials not based on education research results.[13]

The PTRA (Physics Teaching Resource Agent) program, sponsored by the American Association of Physics Teachers and funded by the National Science Foundation, has provided research-based workshops and curricular materials for in-service physics and physical science teachers since the 1980s.[14] Although peer-reviewed studies of the effectiveness of these workshops have yet to be published, preliminary research data suggest that students of long-term workshop participants make gains in physics content knowledge that are significantly larger than those made by students of non-participants.[15]

The programs described above are all specifically targeted

8. Eugenia Etkina, "Pedagogical content knowledge and preparation of high school physics teachers," *Physical Review Special Topics - Physics Education Research* **6**, 020110-1–26 (2010).
9. S. J. Pollock, "A longitudinal study of the impact of curriculum on conceptual understanding in E&M," in *2007 Physics Education Research Conference [Greensboro, North Carolina, 1-2 August 2007]*, edited by Leon Hsu, Charles Henderson, and Laura McCullough, AIP Conference Proceedings **951** (AIP, Melville, NY, 2007), pp. 172-175; Valerie Otero, Steven Pollock, and Noah Finkelstein, "A physics department's role in preparing physics teachers: The Colorado learning assistant model," *American Journal of Physics* **78**, 1218-1224 (2010).
10. Kara E. Gray, David C. Webb, and Valerie K. Otero, "Are Learning Assistants better K-12 science teachers?" in *2010 Physics Education Research Conference [Portland, OR, 21-22 July 2010]*, edited by Chandralekha Singh, Mel Sabella, and Sanjay Rebello, AIP Conference Proceedings **1289** (AIP, Melville, NY, 2010), pp. 157-160; Kara E. Gray, David C. Webb, and Valerie K. Otero, "Effects of the Learning Assistant experience on in-service teachers' practices," in *2011 Physics Education Research Conference [Omaha, Nebraska, USA, 3-4 August 2011]*, edited by N. Sanjay Rebello, Paula V. Engelhardt, and Chandralekha Singh, AIP Conference Proceedings **1413** (AIP, Melville, NY, 2012), pp. 199-102.
11. Mike Ross, Ben Van Dusen, Samson Sherman, and Valerie Otero, "Teacher-driven professional development and the pursuit of a sophisticated understanding of inquiry," in *2011 Physics Education Research Conference [Omaha, Nebraska, USA, 3-4 August 2011]*, edited by N. Sanjay Rebello, Paula V. Engelhardt, and Chandralekha Singh, AIP Conference Proceedings **1413** (AIP, Melville, NY, 2012), pp. 327-330.
12. Douglas Huffman, Fred Goldberg, and Michael Michlin, "Using computers to create constructivist learning environments: Impact on pedagogy and achievement," *Journal of Computers in Mathematics and Science Teaching* **22**, 151-168 (2003); Douglas Huffman, "Reforming pedagogy: Inservice teacher education and instructional reform," *Journal of Science Teacher Education* **17**, 121-136 (2006).
13. Bat-Sheva Eylon and Esther Bagno, "Research-design model for professional development of teachers: Designing lessons with physics education research," *Physical Review Special Topics - Physics Education Research* **2**, 020106-1–14 (2006).
14. Larry Badar and Jim Nelson, "Physics Teaching Resource Agent program," *The Physics Teacher* **39**, 236-241 (2001); Teresa Burns, "Maximizing the workshop experience: An example from the PTRA Rural Initiatives Program," *The Physics Teacher* **41**, 500-501 (2003).
15. Karen Jo Adams Matsler, *Assessing the Impact of Sustained, Comprehensive Professional Development on Rural Teachers as Implemented by a National Science Teacher Training Program*, Ed.D. dissertation (unpublished), Argosy University, Sarasota, Florida, 2004. Also see the 2010 NSF Final Report for the AAPT/PTRA Rural Project, prepared by K. J. Matsler, available at: http://www.aapt.org/Programs/projects/PTRA/upload/2010-NSF-Final-Report.pdf.

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at high school physics and physical-science teachers. However, outcomes reported in studies of similar programs that focus on preparation of elementary-and middle-school physical-science teachers are consistent with the results discussed here. These studies offer further support for the promise of the research-based instructional methods recommended in this Report for education of future physics teachers.[16]

16. For example, Fred Goldberg, Valerie Otero, and Stephen Robinson, "Design principles for effective physics instruction: A case from physics and everyday thinking," *American Journal of Physics* **78**, 1265-1277 (2010).

Summary

The research investigations summarized here are relatively small in scale. However, their number, diversity, and consistency of outcome provide substantial evidence for the effectiveness of the physics teacher education methods recommended in this Report. They are also consistent with the long-standing practices and research findings of physics teacher education programs in many other countries that have demonstrated student learning outcomes superior to those observed in the United States.[17] The literature on physics teacher education both in the U.S. and around the world indicates clearly that physics teacher education programs *can* be effective if they are thoroughly grounded in physics education research and sharply focused on developing expertise with physics-specific pedagogy.

17. See Chapter 1 of this Report as well as Meltzer, "Research on the education of physics teachers."