Research on the education of physics teachers

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The focus of this review is on physics teacher education in the United States. Research on "pedagogical content knowledge" in physics addresses the understanding held by prospective and practicing teachers regarding students' ideas in physics, effective teaching strategies for specific physics concepts, and methods of assessing students' physics knowledge. Courses designed for physics teachers focus on probing and strengthening knowledge of research results regarding students' physics ideas, and of ways to apply that knowledge to effective instruction. Programs for practicing ("in-service") physics teachers have been prevalent since the 1940s; the few relevant research reports suggest that some of these programs may improve teachers' physics knowledge and teaching enthusiasm. More recent research indicates that some current in-service programs lead to significant improvements in learning by students taught by participants in these programs. Research on programs for prospective ("preservice") physics teachers is a more recent phenomenon; it indicates that those few programs that incorporate multiple courses specifically designed for physics teachers can strengthen participants' potential or actual teaching effectiveness. The broader implications of worldwide research on programs for physics teacher education are that several program characteristics are key to improving teaching effectiveness, including (1) a prolonged and intensive focus on active-learning, guided inquiry instruction; (2) use of research-based, physics-specific pedagogy, coupled with thorough study and practice of that pedagogy by prospective teachers; and (3), extensive early teaching experiences guided by physics education specialists.

I. INTRODUCTION: THE CHALLENGE OF RESEARCH IN PHYSICS TEACHER EDUCATION

The focus of this review is on physics teacher education in the United States. We begin with a discussion of the disparity between research on physics teacher preparation in the U.S. and research done abroad, followed by an exploration of the specific challenges that make research in this field particularly difficult. In Section II there is a general discussion of research that has been done on helping teachers develop skill in teaching physics, as opposed to developing physics content knowledge or general skill in teaching. (This type of content-specific skill is termed "pedagogical content knowledge.") In Section III there is a description of the research that has been conducted on specific courses for physics teachers, as distinct from other research related to more extensive teacher preparation programs that generally include multiple courses and program elements. The focus in Section III is on courses developed in the United States, but also included is a brief survey of such courses that have been developed elsewhere. In Section IV we examine programs for practicing (in-service) physics teachers in the United States; such programs have been a distinctive feature of the educational landscape for more than 50 years. In Section V, we review research reports on programs for prospective (preservice) physics teachers in the United States. We conclude in Section VI with a brief overview of the major insights gained from research on the education of physics teachers, as well as implications of this work for future advancements in the field.

A. Physics teacher education in the United States and the world

Several hundred research papers dealing with the education of physics teachers have been published in English-language journals worldwide. However, only a small fraction deal with the education of preservice (prospective) or in-service (practicing) high school physics teachers in the United States. There are several related reasons. First, the nature and role of secondary-school physics education in the United States is quite different from that in many other countries. For example, physics has typically been taught as a one-year course in the U.S. by teachers who primarily teach courses other than physics.[1] In many other countries physics is (or has been) taught as a multi-year sequence of courses by teachers who specialize in physics. In those countries, the need for research to inform and support the preparation of such specialist teachers has long been recognized and encouraged. Moreover, outside the United States, many or most physics teacher preparation programs are led by research faculty who specialize in physics education and who often have extensive high school teaching experience; this is not the case in the U.S. In addition, very few U.S. teacher preparation programs incorporate courses or major activities that focus *specifically* on the teaching of physics. In many other countries, by contrast, the course of study includes a specific focus on physics pedagogy.[2] These specialized courses and programs have provided a fertile ground for research by non-U.S. physics education faculty. Consequently, most physics research faculty who focus on teacher education are located outside of the U.S. and it is they who originate the majority of research investigations related to physics teacher education. In the U.S., most physics education researchers have necessarily focused on other areas of interest.

An example of recent research on physics teacher education outside the U.S. is a paper by Eylon and Bagno on an Israeli program for in-service teachers. It is reprinted in this book because, although the context is quite different from that in the U.S., the researchers provide detailed descriptions and documentation of physics-specific practices that have substantial potential for effective adaptation with physics teachers in the United States.[3] Although general principles both of pedagogy and of science teaching are also relevant to physics teachers, these do not deal with the specific pedagogical issues arising from physics as a distinct area of study. It is those physics-specific issues that are the focus of this review and of this book.

B. Practical challenges to research in physics teacher education

Many of the obstacles to effective research in this field are inherent in the nature of the field itself, that is: most projects and activities aimed at improving physics teacher education are treated as practical, applied problems and not as research projects *per se*. (This holds true both for U.S. and non-U.S. work, although research aspects are generally given greater weight in work done outside the U.S.) Any research that is done is generally considered secondary to the primary objective of near-term improvements in program outcomes, however those might be defined. The focus is usually on overall program effectiveness, not on close examination of individual program elements. Assessment and evaluation—such as there are—tend to be on broad program measures. Multiple and mutually influencing elements of courses or programs are often simultaneously introduced or revised, making assessment of the effectiveness of any one particular measure difficult or impossible. Program revisions are generally based on practical experience, interpretations of the literature, and plausible hypotheses, and not on tested or validated research results. Documentation of changes in practice or outcomes is often unreported and rarely very thorough; even more rarely is there documentation of tests of the effectiveness of these changes.

The reasons for this "practical" orientation—in contrast to one that might be more closely tied to research—are diverse, albeit interconnected. An important consideration is that most teacher educators are practitioners whose primary interest is in improving practice and not necessarily in carrying out research on that practice. Research is viewed as time-consuming, costly, and inconclusive, and generally as offering fewer prospects for practical improvements than work based on intuition, experience, and sound judgment. Those who provide funding for teacher education seem to share this viewpoint, since funding for innovative teacher education projects generally does not envision nor allow for a substantial research effort to be incorporated in the program design. Since the costs of careful research in this field are often felt to be prohibitively high, it is generally conceded that evaluation efforts should be serious but not necessarily extensive, long-term, or in-depth. A major consideration is time: multiple cycles of testing are often impractical when a project extends over a two- or three-year period as is frequently the case. Furthermore, enrollments in courses targeted specifically at pre- or in-service physics teachers are usually low, making it difficult to draw conclusions that have high levels of statistical significance.

It may be helpful to consider what sorts of elements are required to make a research report on teacher education most useful for others who wish either to put into practice or to test independently some of the findings claimed by the researchers. In order for other practitioners or investigators to reproduce effectively the work being assessed, detailed descriptions of the instructional activities would have to be provided, including specific information regarding the tasks given to the students and the methods employed for accomplishing those tasks. Samples of curricular materials would need to be provided in the report or made available elsewhere, the instructor's role would have to be made clear, and samples of student responses to typical quiz, homework, or exam questions would be needed. In order to assess whether the educational objectives have been met, those objectives would have to be explicitly identified and benchmarks specified that could indicate whether and to what extent the objectives had been achieved.

Despite the large number of published reports regarding physics teacher education around the world, few of them include all of the desirable elements identified in the previous paragraph. This is largely true for reports originating from outside the United States, as well as for reports of U.S. work. In any case, since important contextual factors often differ significantly from one institution or region to another, even clear and detailed reports of programs in one nation might have only limited applicability in another nation's context. Consequently, those who are responsible for implementing teacher education in physics must attempt to synthesize results from a large number of studies and draw from them the appropriate implications regarding their own local situation.

Despite these various challenges to research in physics teacher education, the published literature does provide substantial guidance in defining important themes and outlining key findings in the field. The remainder of this review will provide a brief sketch of these themes and findings. It is intended to help place the papers in this book within a context that allows their significant contribution to be more readily apparent. The focus will be on peer-reviewed research related directly to physics teacher education in the United States. As will become evident, almost all of this research relates to evaluations and assessments of specific teacher preparation programs or courses. An extensive bibliography that includes relevant books, reports, and other non-peer-reviewed materials related to this topic may be found in the Report of the National Task Force on Teacher Education in Physics.[4] For the most part, the multitude of published reports regarding physics teacher education programs outside the U.S. will not be discussed in this review apart from mention of several exemplars. Nonetheless, some attention to the non-U.S. work is essential for providing an adequate perspective on the full scope of work in this field.

We continue this review by focusing on those aspects of pedagogical expertise that are specific to the field of physics; this form of expertise has come to be called "pedagogical content knowledge" in physics. Then we turn to courses that have been developed specifically for the benefit of prospective or practicing physics teachers. These courses incorporate various elements of pedagogical content knowledge, as well as physics subject matter taught in a manner intended to be particularly useful to teachers of physics. Finally we examine research on broader programs of physics teacher education in the U.S.; these programs generally incorporate multiple courses or program elements that are designed with a specific focus on the education of physics teachers.

II. DEVELOPMENT AND ASSESSMENT OF "PEDAGOGICAL CONTENT KNOWLEDGE" IN PHYSICS

This section addresses research that has been done in relation to physics teachers' knowledge and skills insofar as they relate explicitly to the teaching of physics. Research on the development of physics teachers' general physics content knowledge is usually discussed in reports on courses, or programs of courses, that have been designed for and targeted at prospective and practicing physics teachers; these courses and programs are reviewed in Sections III-V below.

A. Definition of Pedagogical Content Knowledge (PCK)

In 1986 Lee Shulman introduced the term "Pedagogical Content Knowledge" (PCK) to the education literature and this idea has had particularly strong resonance among science and mathematics educators. PCK in science refers to an awareness of, interest in, and detailed knowledge of learning difficulties and instructional strategies related to teaching *specific* science concepts, including appropriate assessment tools and curricular materials. It refers to the knowledge needed to teach a *specific topic* effectively, beyond general knowledge of content and teaching methods. As described by Shulman, this includes *"… the ways of representing and formulating a subject that make it comprehensible to others…an understanding of what makes the learning of specific topics easy or difficult … knowledge of the [teaching] strategies most likely to be fruitful …"*[5] When defined in this way, physics PCK refers to a very broad array of knowledge elements dealing with curriculum, instruction, and assessment that, in principle, extends to all major topics covered in the physics curriculum.

A major challenge in physics teacher preparation is that no currently accepted, standardized instruments exist with which to measure or assess a physics teacher's PCK. Much of the published research focuses instead on more modest goals of documenting aspects of teachers' PCK or of assessing specific elements of it. In this context, researchers have most often focused on investigating teachers' knowledge of students' reasoning processes in physics, with specific reference to knowledge of students' confused or erroneous ideas about specific physics principles.

B. Documentation of teachers' ideas about physics pedagogy

Studies that simply document, rather than assess or evaluate, teachers' pedagogical ideas on a number of physics topics have been published by the Monash University group led by Loughran and his collaborators in Australia.[6] Their method is to choose a specific topic (e.g., "Forces") and then gather together a group of experienced teachers who begin by generating a set of "Big Ideas" for this topic (e.g., "The net force on a stationary object is zero"). The teachers then collaborate to provide responses to such questions as the following:

- What do you intend the *students* to learn about this idea?
- What are difficulties/limitations connected with teaching this idea?
- What knowledge about students' thinking influences your teaching of this idea?
- What are some teaching procedures/strategies (and particular reasons for using these) to engage with this idea?
- What are specific ways of ascertaining students' understanding or confusion around this idea?

Several other authors have assembled compilations of research results that address some of these questions in the context of university-level physics instruction.[7] However, the particular merit and distinction of the Monash work is that it brings together the combined knowledge and insight of a group of experienced teachers whose ideas have been developed and tested specifically in the context of high school physics.

C. Investigating teachers' knowledge of students' ideas

A common theme in the research literature is to investigate and evaluate teachers' (or prospective teachers') knowledge of students' ideas in physics. For example, Berg and Brouwer[8] asked Canadian high school physics teachers to give predictions of students' responses to a set of conceptual questions in physics. These questions included a prediction of the trajectory of a ball connected to a string, after the string breaks, when it had been swung along a circular path. Other questions included a prediction of the path of a wrench dropped on the moon, and the direction of net force on a ball thrown in the air. It was found that the teachers predicted much higher correct-response rates than those actually observed among their students.[9] Similarly, teachers underestimated the prevalence of specific alternative conceptions among the students. For example, teachers predicted that only 33% of students would claim incorrectly that the direction of the total force on a thrown ball is upward and that there is no force at the top of its path. Actually, 56% of the students had made that claim.

In a similar study, Halim and Meerah[10] interviewed postgraduate student teachers in Malaysia. The teachers were asked to give answers to several physics questions and to provide predictions of how students would answer those same questions. They were also asked how they would teach students to understand the teachers' answers. The researchers found that some teachers were not aware of common incorrect ideas related to the physics concepts and, of those who were, many did not address those ideas through their teaching strategies. An analogous study in Holland in the context of heat and temperature was reported by Frederik et al.,[11] and one in astronomy in the U.S. by Lightman and Sadler.[12]

D. Developing and assessing physics teachers' PCK

There are a variety of approaches to the challenging task of assessing physics teachers' PCK. Perhaps the most "traditional" of these is the observational approach in which teachers' classroom behaviors are assessed according to some standard. Examples of this are discussed by MacIsaac and Falconer,[13] and by Karamustafaoğlu.[14]

Another approach to assessment of physics PCK is to evaluate prospective teachers' interpretations of responses by hypothetical students to specific physics problems. This has proven to be—unsurprisingly—an extremely challenging task to carry out with any reliability. A somewhat more straightforward approach is to assess teachers' ability to predict and describe difficulties students might have with specific physics problems, based on findings in the research literature. The paper included in this volume by Thompson, Christensen, and Wittmann[15] represents one of the best documented studies in this area; it extends work previously reported by Wittmann and Thompson in the context of a course sequence on physics teaching taught in a graduate teacher education program.[16] (This course sequence is described further in the next section.) A program at Rutgers University with more far-reaching goals that also focuses on development of students' physics PCK is the subject of a recent report by Etkina, written for and published in this volume.[17] This program will be discussed further in Section V below.

Several research reports on physics teacher education programs outside the United States have an explicit focus on the development of pedagogical content knowledge and so they will be discussed in this section.

A program in Italy has been described by Sperandeo-Mineo and co-workers. In this program, post-graduate student teachers whose primary background was in mathematics were guided through a 30-hour workshop to become more effective teachers of specific topics in physics. The student teachers carried out laboratory investigations and, guided closely by experienced physics teachers, developed and analyzed teaching and learning sequences for use in high school classes. Evidence indicated that the student teachers made substantial gains in their ability to communicate the targeted physics ideas.[18]

A Finnish in-service program that has similarities to the Rutgers program was described by Jauhiainen, Koponen, and co-workers.[19] This program includes a sequence of four courses that address principles of concept formation in physics, "conceptual structures" in specific topics such as electric circuits and relativity, experimentation in the school laboratory, and history of physics. The impact of this program on participants' physics PCK was assessed through a series of interviews.[20] Similar themes in preservice physics teacher education programs can be found in earlier reports by Nachtigall (Germany)[21] and Thomaz and Gilbert (Portugal);[22] both of these programs stress study of physics-specific teaching methods as well as early student-teaching activities that also are physics specific. They involve hands-on laboratory activities, and require substantial reflection on and review of the teaching experiences that are guided by physics education specialists.

A recent discussion of a German in-service program focusing on physics PCK is given by Mikelskis-Seifert and Bell.[23] An unusually careful study of a different physics education program for in-service teachers in Germany, this one focusing on development and evaluation of teachers' beliefs and behaviors, has also recently been published.[24] A report by Zavala, Alarcón, and Benegas describes a short (3-day) course on mechanics in Mexico that, although focused on physics content, was intended to provide direct experience with research-based, guided-inquiry curricula and instructional methods for in-service physics teachers.[25]

III. RESEARCH ON INDIVIDUAL COURSES FOR PHYSICS TEACHERS

Almost all research reports related to individual courses specifically designed for preservice high school physics teachers originate from outside the United States. A small sampling of such reports will be cited here, along with references to analogous work in the United States. Preservice and in-service programs in the U.S. that may include several such courses are discussed in Sections IV and V, and discussions of courses developed for those programs will be found in those sections.

A. Courses outside the U.S.

As discussed in Section I, many nations have instituted regular courses and programs designed specifically to educate physics teachers. Many of these have been documented in research journals and their impacts on teacher participants have been assessed. Some courses focus primarily on methods for teaching basic physics topics at the high school level, particularly concepts that are found to be difficult by students. Examples of these includes courses in Jamaica,[26] Peru,[27] Italy,[28] Germany,[29] Japan,[30] and South Africa,[31] and, in the context of a laboratory course (for both in-service and preservice teachers), in Finland.[32] In other cases, the courses focus primarily on more advanced physics content but are designed for and taught to an audience that is wholly or primarily composed of preservice teachers. As representative examples, we may cite courses on electricity and magnetism in Denmark,[33] on quantum mechanics in Finland[34] and on modern physics (focusing on relativity) in Italy,[35] as well as problem-solving seminars in Spain and Britain.[36]

B. Courses in the U.S.

In this section we will review all published reports of individual courses for U.S. high school physics teachers that we have been able to locate, apart from courses that are integral parts of broader programs. Such programs and the courses within them are discussed in Sections IV and V of this review.

Among the earliest reports of courses for physics teachers in the U.S. were those in the context of summer programs for in-service high school teachers in the late 1950s, such as those at the University of New Mexico,[37] UCLA,[38] and the University of Pennsylvania.[39] (See also Section IV below.) These reports consistently indicate high degrees of enthusiasm among both participants and instructors, although little attempt is made to evaluate direct impacts on participants' knowledge or teaching behaviors.

Much more recently, Finkelstein has described a course on physics pedagogy for physics graduate students at the University of Colorado which, although not targeted specifically at prospective high school teachers, has the potential to be adapted to such a purpose.[40] In fact, a similar two-course sequence at the University of Maine, mentioned in Section II above, is in part just such an adaptation; it has been described by Wittmann and Thompson[41] and by Thompson, Christensen, and Wittmann.[42] These courses on physics teaching are taught in a graduate teacher education program for both preservice and in-service teachers. The courses at the Universities of Maine and Colorado all incorporate learning of physics content using research-based curricula, as well as analysis and discussion of physics curricular materials and research papers related to those materials. The courses are specifically designed to improve teachers' knowledge and understanding both of physics content and of students' ideas about that content. The authors provide evidence that the courses were at least partly successful in these goals. In all cases, the authors present evidence to show that course participants improve their understanding of physics concepts and, potentially, their ability to teach those concepts.

The physics teacher education program at Rutgers University incorporates a sequence of six separate courses designed specifically for physics teachers; this program is discussed in Section V.

Singh, Moin, and Schunn describe a course on physics teaching targeted at undergraduates at the University of Pittsburgh. They found that the course had positive effects on the students' views about teaching and learning, and noted that at least half of them went into K-12 teaching soon after receiving their undergraduate degree.[43] A graduate-level course targeted at both preservice and in-service teachers has been discussed by Baldwin, who focused on effects of the classroom layout. This course was taught in a graduate school of education.[44]

Most research reports on U.S. physics courses for teachers have focused on courses targeted at prospective elementary school teachers. Such reports—and the dozens of reports of similar courses outside the U.S.—are not covered in this review. Nonetheless, two of the original papers written for this volume and one of the reprints are in that specific context. Loverude, Gonzalez, and Nanes discuss an unusual approach to the use of a "real-world" thematic context to provide a story line in which physics learning activities are set.[45] Goldberg, Otero, and Robinson describe carefully guided student group work centered on experiments and computer simulations designed to help students recognize and grapple with their evolving ideas about physical phenomena.[46] Marshall and Dorward report an investigation of the effectiveness of adding guided inquiry activities to a previously existing course, a considerably easier option than creation of an entirely new course as discussed in the other two papers.[47] All of these papers provide substantial evidence that students in the courses made significant improvements in their understanding of physics concepts. The instructional methods they describe and the curricular materials they employed all have potential value for courses targeted at prospective high school teachers.

IV. EVALUATIONS OF IN-SERVICE PHYSICS TEACHER EDUCATION PROGRAMS IN THE U.S.

Many teacher education programs include both preservice and in-service teacher participants. In this section we will focus on those programs that specifically target in-service teachers, while Section V will address programs that include preservice teachers; these latter programs may also include in-service teacher participants.

A. Early history, 1945–1971

Summer programs designed for in-service (practicing) physics teachers began in the U.S. in the 1940s, initially supported by technology-oriented private companies such as General Electric. These programs were very diverse, but generally included various courses and laboratory experiences aimed at enriching participants' physics knowledge and bolstering their enthusiasm for teaching. One of the earliest evaluations of such in-service programs was in 1955 by Olsen and Waite; they examined the six-week summer fellowship program for physics teachers sponsored by the General Electric Corporation, held at Case Institute of Technology (CIT) each summer from 1947 to 1954.[48] These authors received responses to questionnaires from 60% of former participants in these programs and found that 50% of those respondents reported improved attitude or enthusiasm for teaching as a result of the program. An impressive piece of evidence regarding the indirect effects of the program was a dramatic increase in enrollment at CIT of students taught by these teachers (from 0 to 45 per year), in comparison to the years before the teachers had attended the program. It was also noted that these students had scores on a pre-engineering "ability test" that were well above the average of other CIT freshmen.

Support for summer in-service programs (known as "institutes") by the National Science Foundation (NSF) followed just a few years after NSF's founding in 1950, with low levels of initial, tentative support rapidly expanding during the mid-1950s and, under pressure from the U.S. Congress, exploding to unprecedented levels after Sputnik in 1957.[49] During the period 1959-1966 there were an average of 23 summer physics in-service institutes per year; this was approximately 7% of all summer science in-service institutes held during that period.[50] Published reports of such institutes tended to be merely descriptive, with little attempt at rigorous evaluation or assessment of their impact.[51] At the same time, there was a rapid expansion in NSF-supported development of science curricula, initially aimed primarily at high schools. Arguably the best-known and most influential of these was the physics curriculum project begun in 1956 by the Physical Science Study Committee (PSSC).[52] The other major NSF-supported high school physics curriculum project during this period was Project Physics, often known as "Harvard Project Physics." This curriculum, developed during the 1960s, put a greater emphasis on historical and cultural aspects of physics than did PSSC and was intended for a broader audience.[53]

Starting in 1958, the PSSC project incorporated NSF-supported summer institutes for in-service high school physics teachers as a key element in its dissemination plan. During the initial summer of 1958, five teacher institutes trained 300 physics teachers in the use of the new PSSC curriculum.[54] By the 1961-62 academic year, users of the PSSC course numbered approximately 1800 teachers and 72,000 students. According to surveys, most users felt it was pitched at an appropriate level while a minority felt it was too advanced.[55] By the late 1960s, over 100,000 high school students were using the PSSC curriculum, approximately 20-25% of all students studying physics in high school.[56] In 1965, there were 30 summer physics institutes enrolling from 22 to 71 participants each; about 1/3 of these institutes were specifically dedicated to the PSSC curriculum. In addition to the "physics-only" institutes, many of the multiple-field or general science institutes also offered physics as part of their curriculum.[57]

Although there were a few research reports that examined the effect of the PSSC curriculum on the high school students who studied it,[58] most investigators did not attempt to assess directly the effects of the summer institutes on the physics teachers who attended them. Instead, several reports focused on the characteristics of the teacher participants in PSSC or Project Physics summer institutes.[59] Among the few investigators who did assess the impact of the institutes on the teachers and on the students of those teachers were Welch and Walberg.

Welch and Walberg (1972)[60] reported an unusually careful evaluation of the effects of a six-week summer "Briefing Session" designed to prepare teachers to teach the Project Physics curriculum in their high school classes. When compared to students of teachers in a control group who taught only their regular physics course, students of teachers in the experimental group who attended the Briefing Session reported significantly higher degrees of course satisfaction, while achieving equal levels of performance on physics content tests.

Another investigation by Welch and Walberg (1967) involved an explicit examination of the effects of the summer institutes on the participants themselves.[61] They reported that participants at four summer physics institutes during 1966 (curriculum not specified) made significant gains in understanding of physics content, whereas evidence for gains in understanding of "methods and aims of science" was more ambiguous. However, in a comment on this study by the Physics Survey Committee of the National Research Council, it was noted that "the gains in mean scores…were…so slight that it is doubtful that any long-term effects exist. There also is considerable anecdotal evidence to support the view that summer institutes are often presented at the same breakneck speed that contributes to the necessity for them in the first place."[62]

B. Further developments, 1972–1994

Despite the large numbers of in-service institutes for physics teachers held over the years following their initiation in the 1940s, there continued to be only a few scattered reports in the literature that attempted to assess the impact of these institutes on their participants. (The in-service institute at the University of Washington, Seattle, has been closely integrated with a preservice program since the early 1970s and so it is discussed in Section V below.) In this section we will review, at least briefly, all such reports that we have been able to locate.

In 1986, Heller, Hobbie, and Jones discussed a five-week summer workshop held at the University of Minnesota. They reported that participants enjoyed and valued their experience.[63] In a follow-up report on the same institute, Lippert et al.[64] stated that participants' responses to questionnaires indicated a variety of positive effects of the workshop, including increases in the amount of modern physics taught, implementation of new student experiments, adoption of a more "conceptual" approach in their classrooms, and a dramatic shift away from heavy use of lecture instruction. Many also reported increased enrollment in their classes.

Lawrenz and Kipnis reported on another three-week summer institute for high school physics teachers held at the University of Minnesota in 1987. The institute promoted an historical approach to teaching physics, and it emphasized experimentation through student investigations conducted in classrooms or at home.[65] The researchers found that, in comparison to a control group, students of institute participants were more likely to enjoy their physics classes, to help plan the procedures for the experiments they did in class, and to conduct experiments at home that were not assigned. A very brief contemporaneous report by Henson and collaborators focused on a summer institute at the University of Alabama in 1987 that was specifically targeted at teachers with weak preparation in physics.[66]

A report by Nanes and Jewett in 1994[67] evaluated two four-week summer in-service institutes held in southern California. As in many other similar institutes, participants were also involved in follow-up activities during the academic year. The participants were "crossover" teachers who had weak physics backgrounds and whose expertise lay in other subjects. It was found that the participants made substantial gains on physics content tests (from 40% to 73%, pre- to post-instruction). The participants also reported a large and significant increase in their teaching confidence, as well as in the amount of modern physics taught in their courses.

C. Recent developments, 1995-2011

In recent times, some form of assessment of teacher preparation programs has become more common than in earlier years, in part because it has more often been required by funding agencies. However, there is generally no requirement that such assessments be published in peer-reviewed journals and so, from the standpoint of the research literature under review here, the picture has not changed significantly.

i. University of Washington, Seattle

The oldest ongoing in-service physics teacher education program in the U.S. is at the University of Washington in Seattle, led by the Physics Education Group in the Department of Physics since the early 1970s. The program is unusual—perhaps unique—in that it has involved extensive assessment of teacher learning of content for most of the time since its inception. The program also incorporates extensive preparation for preservice students and so it is discussed in Section V A.

ii. Arizona State University, Modeling Instruction in Physics

Beginning around 1990, Arizona State University instituted a new type of in-service workshop for physics teachers designed on what was called the "Modeling Method" of physics instruction.[68] These Modeling workshops have persisted and expanded to the point where they are today among the most influential and widely attended education programs for physics teachers in the United States. Initial reports regarding results of this form of instruction were included in the 1992 paper that introduced the "Force Concept Inventory" (FCI), the most widely used of all physics diagnostic tests.[69] A more complete account of the design and development of this instructional method, including initial assessment data, can be found in a 1995 paper by Hestenes, Wells, and Swackhamer;[70] that paper is reprinted in this volume. The authors describe Modeling Instruction as based on organization of course content around a small number of basic physical models such as "harmonic oscillator" and "particle with constant acceleration." Student groups carry out experiments, perform qualitative analysis using multiple representations (graphs, diagrams, equations, etc.), conduct group problem-solving, and engage in intensive and lengthy inter-group discussion. Extension of the original workshops into a regular Masters degree program has been discussed by Jackson[71] and, most recently, by Hestenes et al.[72]

There are a number of published reports that provide evidence to support the effectiveness of the Modeling workshops in increasing learning gains of the students whose teachers attended the workshops and/or of the teachers themselves. For example, data provided by Hake in 1998[73] show much higher learning gains on the FCI and other diagnostic tests for students in high school classes taught by teachers who used the Modeling methods instead of traditional instruction. Andrews, Oliver, and Vesenka[74] examined a three-week summer institute that used the Modeling method with both pre-service and in-service teachers. They found learning gains for the preservice teachers were well above those reported using similar tests in more traditional learning environments. Similarly, Vesenka's three-year study reported very high gains on a test of kinematics knowledge for in-service teachers who took two-week workshops based on Modeling Instruction.[75] Strong learning gains and improved teacher confidence growing out of a similar workshop in Ohio were noted by Cervenec and Harper.[76] In addition, improved learning gains in college courses taught with the Modeling method were reported by Halloun and Hestenes (1987)[77] and Vesenka et al. (2002),[78] and in high school courses by Malone.[79]

iii. San Diego State University

Another long-standing program devoted to research-based instruction for physics teachers is that at San Diego State University. Huffman and colleagues have reported evaluations of the Constructing Physics Understanding (CPU) project, targeted at high school teachers, which included two-week-long, 100-hour workshops conducted in the summer and during the following school year. These workshops incorporated inquiry-based investigative activities that made substantial use of computer simulations. The authors found significantly higher FCI scores for students taught by workshop participants than for 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. Surveys indicated that instructional strategies recommended in the National Science Education Standards were used more often by CPU classes than by traditional classes.[80]

Another curriculum developed by the San Diego State group is called Physics and Everyday Thinking (PET);[81] it is aimed more directly at elementary school teachers.[82] A detailed description of this instructional approach along with an assessment of its effectiveness is presented in a paper by Goldberg, Otero, and Robinson, one of the five original papers published in this volume.[83]

iv. The Physics Teaching Resource Agent (PTRA) program

The PTRA program, sponsored by the American Association of Physics Teachers and funded by the National Science Foundation, has provided workshops and curricular materials for in-service physics and physical science teachers since the 1980s.[84] Although peer-reviewed studies of the effectiveness of these workshops are yet to be published, preliminary data suggest that students of long-term workshop participants make gains in physics content knowledge that are significantly greater than those made by students of non-participants.[85]

v. Other programs

A variety of other in-service programs have been discussed in brief reports that focus primarily on program description. Long, Teates, and Zweifel[86] have described a two-year summer in-service program (6-8 weeks each summer) for physics teachers at the University of Virginia. The 31 participants report high satisfaction with the program as well as deeper coverage of concepts in their classes, and increases in the use of labs, demonstrations, and computers in their classes. Other reports on in-service physics programs include those by Escalada and Moeller at the University of Northern Iowa,[87] Jones at Mississippi State University,[88] and Govett and Farley at the University of Nevada, Las Vegas.[89]

V. RESEARCH ON EDUCATION OF PROSPECTIVE PHYSICS TEACHERS IN THE U.S.

There are few reports that provide significant detail regarding preservice physics teacher preparation programs in the United States. (The recent report by Etkina has been mentioned in Section III above.) Here we provide a sampling of reports in the research literature that address programs of this type.

A. University of Washington, Seattle; Physics Education Group

The oldest on-going physics teacher education program in the U.S. is that in the physics department at the University of Washington, Seattle (UW), led by the Physics Education Group. UW began physics courses for preservice high school teachers in 1972, and their summer in-service institutes—originally designed for elementary school teachers—later expanded to include high school teachers as well. In 1974, McDermott reported on an inquiry-based, lab-centered “combined” course for preservice elementary and secondary teachers at UW; the paper is reprinted in this volume.[90] Curricular materials developed for this course formed the progenitor of what later turned into *Physics by Inquiry*,[91] a curriculum targeted at both prospective and practicing teachers. Based on 40 years of intensive research on student learning, with an effectiveness validated through multiple peer-reviewed studies, *Physics by Inquiry* is currently one of the most widely used curricula in physics courses for pre- and in-service K-12 teachers.

Based on work in the UW physics teacher education program, McDermott published a set of recommendations for high school physics teachers that emphasized a need to understand basic concepts in depth, to be able to relate physics to real-world situations, and to develop skills for inquiry-based, laboratory centered learning.[92] In 1990 McDermott emphasized the particular need for special science courses for teachers; that paper is reprinted in this volume.[93] In 2006, she reviewed and reflected on 30 years of experience in preparing K-12 teachers in physics and physical science.[94] At the same time, McDermott et al. documented both content-knowledge inadequacies among preservice high school teachers, and dramatic learning gains of both preservice teachers and 9th-grade students of experienced in-service teachers following use of *Physics by Inquiry* (PbI) for teaching certain physics topics.[95] The second of those 2006 papers is reprinted in this volume. Messina, DeWater, and Stetzer have provided a description of the teaching practicum that gives preservice teachers first-hand teaching experience with the UW program’s instructional methods.[96]

The effectiveness of the *Physics by Inquiry* curriculum in courses for prospective elementary school teachers has been documented by numerous researchers.[97] Of particular interest here are reports that focus on its use for the education of high school teachers. In one of these reports, Oberem and Jasien discussed a three-week summer in-service course for high school teachers. There were no lectures; the course was laboratory-based and inquiry oriented, and used the *Physics by Inquiry* curriculum. Over three years, their students demonstrated high learning gains (relative to traditional physics courses) using various diagnostic tests for topics that included heat and temperature, kinematics, electric circuits, light and optics, electrostatics, and magnetism. Delayed tests administered 6-8 months after instruction found good to excellent retention of learning gains on heat and temperature, and on electric circuits.[98] By contrast, the same authors had reported in 2002 that incoming students in these and similar courses had shown high (30-60%) incorrect pretest response rates on basic questions about heat, temperature, specific heat, and internal energy.[99] A separate study reported an investigation into a grade-11 student's learning of heat and temperature concepts using the *Physics by Inquiry* curriculum, documenting advances in conceptual understanding.[100] Together, these reports suggest that teachers who learn with the *Physics by Inquiry* curriculum may be able to adapt the materials for direct use in high schools; anecdotal reports provide further support for this conjecture.

B. University of Colorado, Boulder; Learning Assistant program

The University of Colorado, Boulder has pioneered a program in which high-performing undergraduate students are employed as instructional assistants in introductory science and mathematics courses that use research-based instructional methods. These students, known as "Learning Assistants" (LAs), are required to participate in weekly meetings to prepare and review course learning activities, and also to enroll in a one-semester course specifically focused on teaching mathematics and science. Program leaders have documented improved learning of students enrolled in classes that make use of Learning Assistants and the program has come to be highly valued by faculty instructors.[101] The Learning Assistant program has been used very deliberately as a basis for preparation and recruitment of prospective mathematics and science teachers and, particularly in physics, significant increases in recruitment of high school teachers have been documented during the past five years. A detailed report on the program along with a discussion of the assessment data are provided by Otero, Pollock, and Finkelstein in an original paper written for and published in this book.[102] Follow-up observations and interviews with former participants in the LA program indicate that teaching practices of first-year teachers who were former LAs are more closely aligned with national science teaching standards than practices of a comparable group of beginning teachers who had been through the same teacher certification program but who had not participated in the LA program.[103] A short report of a program at Florida International University based on the Colorado model has been provided by Wells et al.[104]

C. Rutgers, The State University of New Jersey; Graduate School of Education

The physics teacher education program at Rutgers Univesity is described in a paper by Etkina written for and published in this volume.[105] It leads to a Masters degree plus certification to teach physics in the state of New Jersey. It includes six core physics courses with emphasis on PCK in which students learn content using diverse, research-based curricula, as well as design and teach their own curriculum unit. The course sequence includes extensive instruction related to teaching, and assessing student learning of, specific physics topics; course examinations assess the prospective teachers on these specific skills. A variety of evidence is presented to show that the prospective teachers make significant gains in their understanding of physics concepts and of science processes such as experiment design, and that they become effective teachers at the high school level.

D. Reports on other programs

There are a number of other preservice programs for which brief reports have been published, providing descriptions of the courses, course sequences, and strategic plans. Although these programs are, to one extent or another, based on or informed by physics education research, to date the assessments of their impact on participants are very limited and primarily anecdotal, based on self-reports or a few case studies. Programs are listed below in chronological order of most recent published report.

1. Haverford College

Roelofs has described the concentration in education designed for future physics teachers at Haverford College, which includes two courses that provide practical instruction in teaching both classroom and laboratory physics.[106]

2. University of Massachusetts, Amherst

Among the most extensive research-based curriculum projects targeted directly at high school students themselves was the NSF-funded *Minds-On Physics* at the University of Massachusetts, Amherst. This project focused on the production of a multi-volume set of activity-based curricular materials that emphasize conceptual reasoning and use of multiple representations.[107] The materials also formed the basis of a course for undergraduate university students who had an interest in teaching secondary physical science. Mestre[108] has described this course which, in addition to undergraduates, also enrolls graduate students and in-service teachers who are or plan to become secondary-school physical science teachers. The course makes extensive use of graphical and diagrammatic representations and qualitative reasoning, and participants develop activities and assessment techniques for use in teaching secondary physics. Class time is spent in a combination of activities, including class-wide discussions, collaborative group work, and modeling the type of coaching and support that should be provided to high school students.

3. Illinois State University

In 2001 Carl Wenning described the physics teacher education program at Illinois State University.[109] Although the program has evolved since that time, it still retains the distinction of including six courses offered by the physics department (a total of 12 credit hours) that focus specifically on physics pedagogy and teaching high school physics.

4. California State University, Chico

Kagan and Gaffney[110] have described a bachelor's degree program in the physics department at Cal State Chico that incorporates revised requirements for prospective teachers. There are fewer upper-level physics courses included in the program than in the regular Bachelor's degree program; instead, students choose from courses in other sciences in addition to participating in a teaching internship. The authors report a substantial number of graduates of the new degree program; at the same time, the number of graduates in the traditional degree program has been maintained. Consequently, the new program has resulted in a substantial number of additional physics graduates over and above the number who would have graduated solely through the traditional degree program. (However, not all of the graduates in the new program have ultimately entered the teaching profession.)[111]

5. University of Arizona

Novodvorsky et al.[112] have described the preservice physics teacher education program at the University of Arizona that, very unusually, is contained entirely within the College of Science. Case studies suggest that the program has had positive impacts on participants' content knowledge and ability to recognize and articulate teaching goals, with the potential of improving their effectiveness in the classroom.

6. Buffalo State College (State University of New York)

MacIsaac and his collaborators have described an alternative certification, post-baccalaureate Masters degree program in New York State.[113] The program includes summer and evening courses in addition to intensive mentored teaching. Program leaders have found a high demand for the program, requiring them to be quite selective in their admission criteria.

VI. CONCLUSION

The education of physics teachers has been a specific focus of researchers for over 50 years and hundreds of reports on this topic have been published during that time; the great majority of such reports are from outside the United States. A variety of practical and logistical challenges have made it difficult to assess reliably the effectiveness of diverse program elements and courses. Moreover, local variations in student populations and cultural contexts make it challenging to implement effectively even well-tested and validated programs outside their nation or institution of origin.

Nonetheless, certain themes have appeared in the literature with great regularity. Evidence has accumulated regarding the broad effectiveness of certain program features and types of instructional methods. The major lesson to be learned from the accumulated international experience in physics teacher education is that a specific variety of program characteristics, when well integrated, together offer the best prospects for improving the effectiveness of prospective and practicing physics teachers. This improved effectiveness, in turn, should increase teachers' ability to help their students learn physics. These program characteristics include the following:

1. a prolonged and intensive focus on active-learning, guided-inquiry instruction;
2. use of research-based, physics-specific pedagogy, coupled with thorough study and practice of that pedagogy by prospective teachers;
3. extensive early teaching experiences guided by physics education specialists.

With specific regard to developments in the United States, it is possible to discern several promising trends over the past fifty years.[114] Perhaps the single most significant factor during this period has been the development of physics education as a focus of scholarly research in a significant number of U.S. physics departments. This ongoing research has revealed previously underestimated shortcomings in traditional educational practices, and at the same time has provided powerful new tools and techniques for in-depth assessment of student learning in physics. Moreover, physics education research has led to new instructional methods whose increased effectiveness has been repeatedly validated by numerous investigators nationally and worldwide.[115]

As is documented in the references cited in this review, research-based instructional methods and research-validated instructional materials have played an increasingly large role in U.S. physics teacher education courses and programs. At the same time, outcomes measures that grow out of research-based assessment tools—such as, for example, documented learning gains by the students of the new teachers and by the teachers themselves—have provided a degree of reliability for evidence of program effectiveness and guidance for program improvement that has previously been unobtainable. Largely due to these developments, current trends in physics teacher education have much more the character of cumulative, evidence-based scientific work than did the well-meaning efforts of teacher educators a half-century ago.

Most of the world outside the U.S. has accepted the idea that effective education of physics teachers must be based on sound research and led by specialists in physics education. In other nations, these activities have been conducted both in physics departments and in schools of education. For a variety of reasons, it seems unlikely that substantial improvements in the education of U.S. physics teachers can take place without primary responsibility being accepted by physics departments at colleges and universities. In sharp contrast to the situation in some other countries, there is no tradition in U.S. colleges of education that would allow them to take on significant responsibility for preparation of physics teachers in the absence of a clear and unequivocal leadership role on the part of departments of physics. However, if that leadership continues to emerge and to build on the foundation of modern research in physics education, there is great promise for continued future advances in the education of teachers of physics.

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[1]Until 1993 the teaching assignment of most high school physics teachers in the U.S. was primarily in courses other than physics, since few schools had enough physics students to justify hiring a full-time physics teacher. This had been the case since physics first become a regular part of the U.S. high school curriculum in the late 1800s. It wasn't until 2009 that a majority of U.S. physics teachers taught all or most of their classes in physics. See, for example, C. Riborg Mann, *The Teaching of Physics for Purposes of General Education* (Macmillan, New York, 1912), Chap. I; and Susan White and Casey Langer Tesfaye, *Who Teaches High School Physics? Results from the 2008–09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2010), p. 3 (Figure 2).

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