# A Developmental History of Physics Education Research*

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## I. INTRODUCTION

There is an African proverb that says "*Until lions have historians the tale of the hunt will always glorify the hunter*." It seems that reporting history should be a simple matter of ascertaining the facts and recording them. But, of course, it is not that simple. So, in an effort to avoid reporting events from one particular point of view, I collected information from a wide range of sources. What I will generally report here is a synthesis of this information with multiple sources of input used for triangulation. However, in some cases triangulation was not possible and I can only report on input that I received from a single individual.

### A. Methodology

In preparing my responses to the board's questions, I reviewed the few publications and presentations on the history of physics education research (PER) that were available. I focused on the published transcript of a talk given by Arnold Arons at the 1998 Physics Education Research Conference organized by Bob Fuller and held in Lincoln, Nebraska. (Arons, 1998) This was the very first American Association of Physics Teachers (AAPT) and PER conference that I attended and I remember hearing Arnold Arons speak. Bob Beichner has a significant amount of relevant history in his paper entitled *An Introduction to Physics Education Research.* (Beichner, 2009) Lillian McDermott has been working diligently on a soon to be published history of the physics education research group at the University of Washington. (McDermott, 2010-1) This is an exceptionally valuable resource for those interested in the history of the field. David Meltzer is in the process of completing a relevant manuscript entitled *The Origins, Present Status, and Current Trajectory of Research in Preparation of Physics Teachers*. (Meltzer, 2010-2) At the Winter 2010 AAPT meeting held in Washington, DC, Steve Kanim and David Meltzer each gave presentations that contained historical data in a session entitled *Physics Education Research: Solved Problems and Open Questions*. (Kanim, 2010 and Meltzer, 2010-1) Both of these gentlemen shared their slides for those talks with me and they have significantly informed my thinking in regard to this manuscript. Michael Wittman's work on PER history, posted at the PER Central website, including his "PER family tree" was also very helpful. (Wittman, 2010)

I solicited direct responses to the questions posed by the board from a wide range of individuals. My highest priority was to gather input from individuals who have been active in PER for several decades. However, given the nature of the questions the board put forward, I also wanted to gather input from less well established members of the community. I had long telephone conversations with Fred Reif, Lillian McDermott, Dewey Dykstra, Ron Thornton and Stamatis Vo-

kos. I also spoke with Dean Zollman and Joe Redish. Many other people provided me with valuable written input on the specific questions the board asked. These people include:

*Bob Beichner*
(North Carolina State University)
*Hunter Close*
(Seattle Pacific University)
*Dewey Dykstra*
(Boise State University)
*Noah Finkelstein*
(University of Colorado)
*Fred Goldberg*
(San Diego State University)
*David Hammer*
(Tufts)
*Andrew Heckler*
(Ohio State University)
*Ken Heller*
(University of Minnesota)
*Charles Henderson*
(Western Michigan State University)
*David Hestenes*
(Arizona State University)
*Ted Hodapp*
(American Physical Society)
*Steve Kanim*
(New Mexico State University)
*Priscilla Laws*
(Dickinson College)
*Jeffrey Marx*
(McDaniel College)
*Lillian McDermott*
(University of Washington)
*David Meltzer*
(Arizona State University)
*Jose Mestre*
(University of Illinois)
*Eric Mazur*
(Harvard University)
*Julie Schell*
(Harvard University)
*Chandraleka Singh*
(University of Pittsburg)
*Ron Thornton*
(Tufts)
*Carl Weiman*
(Various)
*Michael Wittman*
(University of Maine)

I am very grateful to these people for their input.

### B. Constraints on Scope

In order to keep the scope of this work reasonable, I have made several choices about how to limit my discussions. I will only discuss the development of physics education research in the United States. In addition, my discussions will be focused on the group of individuals that I believe is the target of this study: the community of physics education researchers who, for example, often present their work at national American Association of Physics Teachers (AAPT) meetings or the associated Physics Education Research Conferences (PERC). This community often publishes their findings in the *American Journal of Physics* (*AJP*), *The Physics Teacher* (*TPT*), *Physical Review Special Topics-Physics Education Research* (*PRST-PER*) or the proceedings of the PERCs.

Most of the people in the PER community, as I have defined it here, hold faculty positions in physics departments. A few are located in schools of education. A few are K-12 teachers. Most of the research done by this community focuses on undergraduate students taking physics courses at U.S. institutions. As a result of the choices that I have made in regard to scope, I will be predominately discussing those scholars whose work is relevant to and/or directed toward undergraduate physics instruction in the United States including the education of future scientists, engineers and teachers as well as non-science majors. However, some physics education re-

searchers study younger children, graduate students or larger scale structure like the courses, departments or universities themselves.

I focus the discussion that follows in these ways not only to keep the length of the discussion manageable, but also because this is the only community with which I am very familiar. I understand that there are other communities of scholars who study physics learning and that these communities have contributed to the field in many important ways.

## II. ANSWERS TO QUESTIONS PRESENTED BY THE BOARD

### *A.* In what decade did the phenomenon of physics education research arise, and what was the impetus?

Some people in the field would argue that the phenomenon of physics education research started in the 1960s with the work of Robert Karplus (Berkeley), Fredrick Reif (Berkeley) and Arnold Arons (Amherst then University of Washington), or perhaps even earlier. John Dewey's work in the early 1900s or Jean Piaget's in the 1930s could be considered starting points. A few other people (mostly newer to the field) would argue PER was not a coherent entity, and so did not really exist, until the mid-90s. However, both of these opinions are outliers. Most of the early scholars in the field, those who have studied our history and the majority of people with whom I communicated agree that the discipline arose in the 1970s. This date is consistent with both the personal accounts of when early researchers recall they began engaging in closely related activities and with the point in time when U.S. publication rates for PER related articles stabilized at something greater than approximately zero. (Heller,2010; McDermott,2010-1; Reif,2010 and Zollman,2010). See Fig. 1. (Kanim,2010)

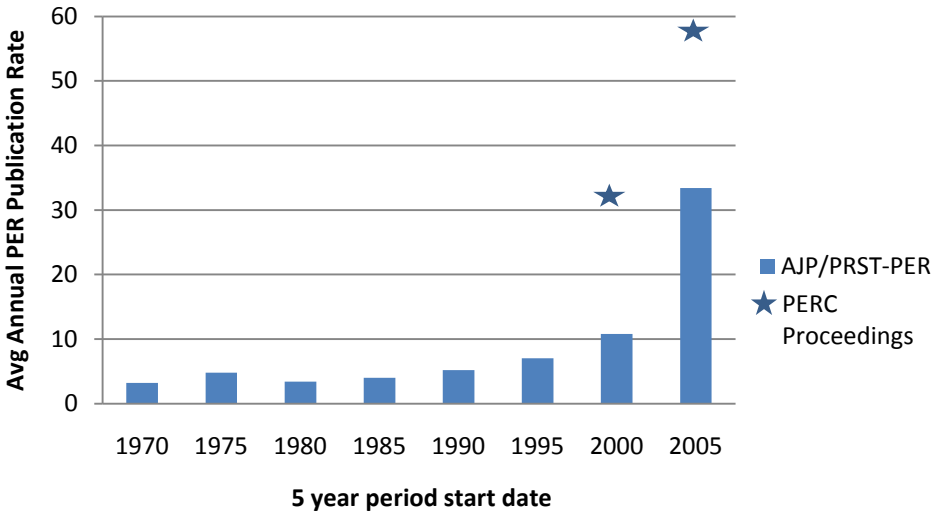


**FIGURE 1:** Average annual publication rates of PER in the journals that are now the most common U.S. publication venues over various five year periods. For example, the average annual publication rate for PER (in the American Journal of Physics or AJP) was about 3 papers per year from 1970-1974(the first bar on the left). Years 2005-2009 (the last bar on the right) include publications in AJP and Physical Review Special Topics-Physics Education Research (PRST-PER). It is important to note that it was difficult to get PER published in the AJP during the first 20-25 years covered by this graphic. Many PER papers were published elsewhere during this period.

What was the impetus for the development of the field? During the 1970s, and the years immediately preceding that decade, there was a growing realization that students were not learning what was taught. (Thornton,2010; Reif,2010; Zollman,2010). For example, Arnold Arons said:

> *"After having spent the years of the second world war studying explosion phenomena and shock waves, I went back to academic work at my alma mater, Stevens Institute of Technology in Hoboken, New Jersey and I quickly began to see, (having an ego deflating experience which most of you probably share with me) to discover that my lucid lectures and demonstrations were depositing virtually nothing in the minds of the students….."*(Arons,1998)

In addition, according to Fred Reif and others, federally funded curriculum projects like the Physical Sciences Study Committee (PSSC) and Science Curriculum Improvement Study (SCIS) were an additional impetus for the birth of the field. (Finlay,1962; Fuller,2002; Reif,2010) Reif suggests that such projects got practicing physicists, some who would otherwise never have been tempted to work on these problems, interested in education. In addition, Reif believes that the grant money associated with these federally funded curriculum projects lent prestige to the undertaking that was necessary if the work was to be valued. (Reif,2010)

In addition, I believe that the launch of Sputnik left government official and educators alike with a new (perhaps nebulous) sense that the nation could no longer allow learning physics to be left to only the few who "have what it takes" to make it successfully through our physics courses. Physics was beginning a transition from *Gatekeeper* course to *Gateway* course.

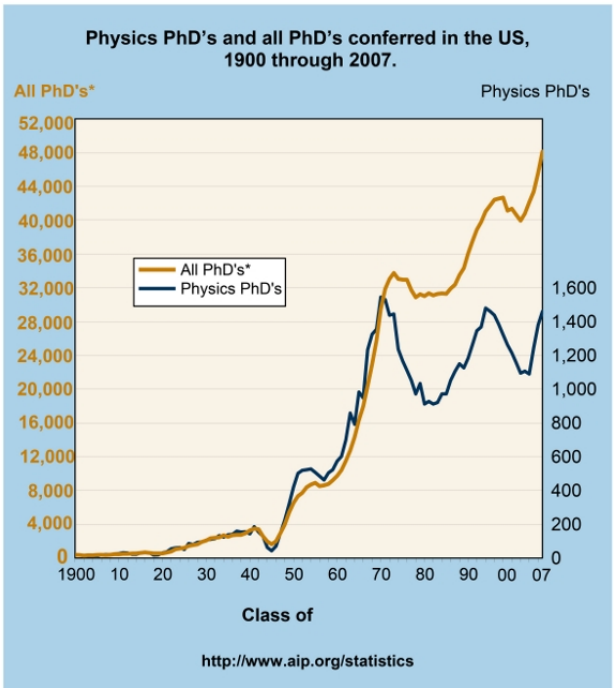


**FIGURE 2.** PhD production in the United States. (AIP,2010)

The same "Sputnik Era" outlook that had motivated the federal government to fund and scientists to focus on curriculum development for K-12 science instruction had also resulted in a significant boost in the production of physics PhDs. See fig. 2. (AIP,2010) As a result, I think that there was a critical mass of fairly young, well trained physicists available and willing to investigate the novel but interesting opportunities the field of PER had to offer.

### *B.* Where were the first generation of physics education research scholars located?

In answering this question I have taken "first generation" to mean those individuals who were working on PER related problems in the 1970s and early 1980's. Michael Wittman has produced a "PER Family Tree" which has not been checked for complete accuracy, but which does give one a good sense of how individuals and groups are related and the relative size of various PER groups in the country. (Wittman,2010-1)

**First Generation Locations (1970s and early 1980s)**

***Pre 1970:***
Berkley (Fred Reif, Jill Larkin and Bob Karplus-**Physics)**

***1970s and Early 1980s:***
Kansas State University (Jacqueline Spears, Dean Zollman-**Physics**),
University of Massachusetts at Amherst (John Clement-**Education**, Bill Gerace-**Physics**, Jack Lockhead-**Physics**, Jose Mestre -**Physics)**,
University of Nebraska-Lincoln (Bob Fuller-**Physics**),
University of Washington (Arnold Arons and Lillian McDermott-**Physics**)

**Second Generation Locations (Late 1980s and Early 1990s)**

Arizona State University (David Hestenes-**Physics**),
Dickinson/Tufts/U of Oregon (Priscilla Laws, Ron Thornton, David Sokoloff-**Physics**),
Harvard University (Eric Mazur-**Physics**),
Indiana-Purdue University Fort Wayne/Creighton (David Maloney-**Physics**),
Indiana University (Richard Hake-**Physics**),
Ohio State University-Marion (Gordon Aubrecht II-**Physics**),
North Carolina State (Bob Beichner-**Physics**),
Rutgers/Ohio State /New Mexico (Alan Van Heuvlan-**Physics**),
San Diego State (Fred Goldberg-**Physics** and **Education**),
University of Illinois-Urbana (Bruce Sherwood-**Physics**),
University of Maryland (Joe Redish and Jack Wilson -**Physics**),
University of Minnesota-Twin Cities (Ken and Pat Heller-**Physics and Education**)

### *C.* When were the first generation of PhD and postdoctoral programs for education researchers in physics established, and where were they?

There is a tradition in many physics departments of allowing a doctorial student to get a PhD based on any research topic they chose-provided they can secure an advisor and organize a thesis defense committee. Hence, there were (and still are) isolated PhDs in physics granted for PER based thesis work at universities without any organized PER group.

In addition, at some universities it was/is possible to make joint arrangements with the Department of Physics and School of Education for a personalized Ph.D. in Physics Education Research. Perhaps the first such degree was awarded to Pat Heller in 1977. Encouraged by Arnold Arons when she worked with him at the University of Washington, she entered the College of Education at the University of Michigan for a self-designed PhD in Physics Education while she held a teaching assistantship in the Physics Department. (Heller,2010) This model of a PhD in Education but an "intellectual home" in the physics department is not an uncommon one.

The first formal PhD *program* in something closely resembling PER was the SESAME program (Graduate Group in Science and Mathematics Education) at Berkeley. (Fuller,2002; Reif,2010; Karplus,2010) This interdisciplinary program was started in the late 1960s by Karplus and Reif. It is still in existence today. Students get PhDs in Science or Mathematics education.

The first organized PER group to provide access to a PhD in physics for physics education research (i.e. the PER group is completely housed within the physics department) was the University of Washington (Lillian McDermott). David Trowbridge was the first to graduate from this program. He received his PhD in 1979. In 1985, Peter Schaffer joined the group as a graduate student. In 1993 he became the Washington group's first postdoctoral scholar. Paula Heron joined as a postdoctoral scholar in 1995. To date there have been 22 PhDs in PER award through the University of Washington group. (McDermott,2010-1) Schaffer and Heron were likely the first PER postdoctoral scholars in the country.

To my knowledge, there have not been any formal postdoctoral programs for those wishing to enter PER. The program that comes closest was the National Science Foundation's Postdoctoral Fellowship in Mathematics,Science, Engineering and Technology Education (PFSMETE). The PFSMETE program had the following stated objectives:

- to prepare Ph.D. graduates in science, mathematics, engineering and technology with the necessary skills to assume leadership roles in SMET education in our Nation's diverse educational institutions, and
- to provide opportunities for outstanding Ph.D. graduates to develop expertise in a facet of science education research that would qualify them for the new range of educational positions that will come with the 21st century. (NSF,1999)

It can be argued this program was very successful in regard to building PER capacity. Several of our young, R-1 faculty were PFSMETE scholars (e.g. Noah Finkelstein-tenured at University of Colorado, Leon Hsu-tenured at University of Minnesota and Scott Franklin-tenured at Rochester Institute of Technology). Given that so many physics education researchers emigrate from other fields of physics research, the PER PhD production pipeline is fragile and a "real physics PhD" is never frowned upon by the physics faculty at an R-1 institution, I believe the PER community should push for the reinstatement of this program.

### *D.* How was physics education research initially viewed by scholars in the discipline and by others such as educators or social scientists?

Physics Education Research was initially either completely dismissed or viewed with great skepticism (even hostilely) by almost all other physicists. Some physicists who fancied themselves good teachers felt threatened. Others felt that the work was simple and therefore not appropriate for a physicist to do. (Arons,1998; Heller,2010; Reif,2010) Consider the quote from Arnold Arons (1998) that is copied below.

> *"I was elected in the early sixties to the commission on college physics, which was then active in catalyzing curriculum development at the college and university level. Zacharias and Friedman, two members of the committee, were the people responsible for PSSC physics. Zach (Zacharias) in particular, over and over again in the commission meetings, said we ought to be doing research in physics education. But when people like that talked about research in those days, they didn't mean the kind of thing that [PER researchers] are engaged in at all. What they meant was, refining the delivery systems, the exposition, the text presentation, lecture presentation, the films and so forth, to the point that where they were so clear and so perfect that any passive student mind would assimilate them simply by having it drop in. That was what research was going to be—delivery—and there was no conception of listening to what the students said when you gave them the opportunity to reflect or talk about something. I was very young then you know; take that into consideration. Sitting on the college commission were Zacharias and Ed Condon and Dick Crane and Bob Leighton and Matt Sands from Cal Tech, people of that variety. All senior to me. When I, on a couple of occasions, murmured that research might consist of finding out what the student learning problems were, the response that I got, in particular from one of the senior physicists on the commission, a man for who I had and still have tremendous respect, much senior to me, said, "Oh well, look, you're talking about gimmicks of your own creation and variety—that is not going to add anything to this enterprise." He, like the others, was thinking in terms of delivery systems. There is an example of what it was like back then."*
>
> (Arons,1998)

No one who provided input for this paper felt that social scientists have been hostile toward physics education research. However, several people conveyed that they sensed social scientists had (and perhaps still have) little respect for the work done in the field of PER believing that physics education researchers ignore the work of social scientists, PERs' methods are crude or our choices of topics are superficial. Educators (taken to mean practicing teachers), on the other hand viewed the field quite favorably since many PER results are consistent with the intuitions and experiences of good teachers. Curricular materials and approaches developed based on PER were (and still are) often sought out for use.

***E*. Has the status of physics education research changed over time? If so, how and why?**

In responding to this question I refer the reader back to the quote from Arons above. Given such a reminder of the status of the field 50 years ago, I find it hard, on any grounds, to argue that the status of PER has not changed. It is my opinion that the field is still not widely accepted in R-1 physics departments as an appropriate form of physics research. However, I would also argue that the field is quite broadly valued (in many R-1s as well as less research oriented institutions). This is evidenced by the significant number of "PER consumers" who attend our workshops and meetings. As one highly respected member of the PER community put it:

*"[PER] has clearly become increasingly respectable, although I would say it is still far from being a mainstream physics discipline. My undocumented opinion as to why that has happened has been the growing amount of reproducible quantitative data that is readily acquired in regular classrooms. I have in mind the use of the FCI, BEMA* (Ding, 2006*), etc. and the research results based upon those coming out of regular classrooms all over the country.*

*I also think that Eric Mazur has played a very large part in making PER "respectable" in physics departments. He can communicate with traditional physics faculty considerably better than can any hard core PER researchers. Over the years I have heard many traditional physicists who have mentioned hearing Eric and finding his results compelling. Also, the message that he brings that is a combination of a) data showing serious problems with traditional teaching even for Harvard students, and b) a relatively easy method that any physics instructor can implement to improve the results, is particularly compelling."*

***F*. What are some key indicators of the changing status? (e.g., T & P requirements, publication of physics education research in disciplinary journals, the establishment of physics education research journals, etc.)**

All of the examples listed by the board in this question were cited by respondents as indicators of the changing status of PER. However, the significant increase in the number and quality of publishing opportunities for physics education researchers, especially the launch of the *Physical Review Special Topics-PER* journal, was the most commonly and clearly cited. Forty years ago it was difficult to get PER published anywhere. (Arons,1998; Reif,2010; McDermott,2010-1) Now it is no longer remarkable for physics education research to be published in *Physics Today* or even *Science* magazine. At least two PER faculty (Sanjay Rebello and Noah Finkelstein) have received NSF Career grants.

Other clear indications of the improved status of the field include the fact that we now have more than 75 tenured or tenure-track faculty who are active in the PER community (publishing papers and presenting at meetings). This is an order of magnitude increase over the numbers in the 1970s. Many (perhaps most) of these individuals received tenure and promotions based on their PER work.

The annual PER conference typically has attendances that approach 200 people with an average of about 70 associated proceedings publications each year. Twenty years ago there was no annual PER conference and therefore, there were no proceedings.

### *G.* What theoretical frameworks have guided the development of physics education research?

It could well be argued that PER was born of a Piagetian framework both in regard to ideas of concept formation and use of clinical interviews to determine them. Other theoretical frameworks that were mentioned by multiple individuals include social constructivism (ala Vygotsky); expert/ novice differences and a cognitive apprenticeship model as applied to development of problem solving abilities; and "knowledge in pieces" (ala diSessa). (diSessa,2000; Smith,1993; Social Constructivism,2010)

I was struck by the range and nature of responses that I received in regard to this question. There were several very knowledgeable physics education researchers who answered along the lines of "what *is* a theoretical framework?" when I asked this question of them. Perhaps the lack of any consensus on this issue is an indication that, as Fred Reif said, we have no theoretical frameworks in the field of PER. Reif asserted that PER may have bits and pieces of frameworks but argues that there is not yet any coherent framework which guides research. He further argued that we should be concerned about this since the field needs a framework to make significant progress in the future. (Reif,2010) Other leaders in the community, including Lillian McDermott, argue that a theoretical framework is not necessary for productive research now or in the foreseeable future. (McDermott,2010-3) Joe Redish may be the current leading proponent of development of a theoretical framework for PER. In 1999/2000 he took a sabbatical in Berkeley. He returned and soon produced a paper that some consider seminal. It was written for the PER based Fermi school held in Italy during the summer of 2003 and is entitled "A Theoretical Framework for Physics Education Research: Modeling Student Thinking". (Redish,2004).

### *H.* Has the focus of physics education research changed over time?

Yes, the focus of physics education research has changed over time. How quickly the focus is changing is not clear, but it has certainly changed.

The field of PER started out with a focus on student misconceptions. As the research into students' beliefs about physical principles progressed, the term "misconceptions" fell out of favor with some researchers. As McDermott explains, the word "misconception" trivialized the problem by giving the impression that incorrect student thinking was easy to correct.(McDermott, 2010-3) Research projects in this area might involve interviewing students to determine what ideas they have about physics topics, development of (and action-research with) conceptual assessments (for example, the FCI), and/or devising curricular materials based on research findings (*Tutorials in Introductory Physics*, Peer Instruction). (Hestenes,1992; Mazur,1996; McDermott,2001) Research of this type was (and still is) quite applied, with obvious application to improving college level physics instruction.

Over the course of the last 10 or so years, the predominate focus of PER has shifted into other areas including thinking about the impact of instruction on student attitudes toward science (and visa-versa), attempting to understand the structure of knowledge (e.g. Knowledge in pieces/resources and expert/novice differences) and applying methodologies from cognitive science (e.g. functional MRI and eye tracking) to learn about physics cognition. Others (Henderson and Dancy for example) are looking into issues associated with why faculty do or do not adopt PER based curricular materials. (Dancy and Henderson, 2008)

In general, much PER research has shifted away from the "applied research" end of the spectrum and not everyone is comfortable with this change. The fear is that we will lose our base of support in physics departments if the application of our work in college level courses is not obvious. In addition, the wide diversity of research interested in a relatively small field makes the PER community seem a bit adrift to some. Consider the comment below from one promising young researcher:

> *"[PER research] seems to have become more and more fragmented, quite divergent. This may be a natural consequence of increasing number of researchers, but there seems to be a lack of consensus on priorities and goals of the field."*

## *I.* What were the key milestones in the development of physics education research?

### *i. Pre 1970 Milestones in PER*

The first milestone event for the physics education research community in the United States was the 1930 split of what is now the American Association of Physics Teachers (AAPT) from the American Physical Society (APS). The AAPT is unquestionably the home organization for the U.S. PER community. Due to the smaller size of the AAPT organization (relative to the American Physical Society), and its focus on physics education, it is well suited to PER. In my opinion, it is hard to imagine how the PER community could have grown so without the AAPT meetings serving as an effective mechanism for the exchange of information. The AAPT's response to our needs has at times been slugging, but they have responded. (Redish,2010; Reif,2010; Thornton,2010; Vokos,2010; Zollman,2010).

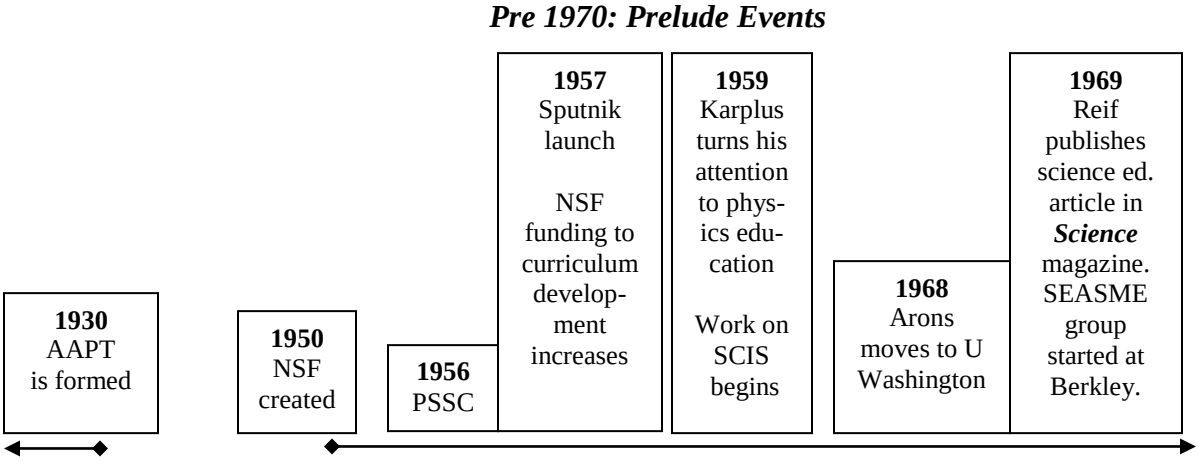


**FIGURE 3.** Key milestones in PER before 1970.

Other early milestone events included the post-Sputnik federal funding of science curriculum development. The Physical Sciences Study Committee (PSSC) was formed in 1956 by Jerrold Zacharias (MIT physics).(Finlay,1962) Robert Karplus (Berkeley physics) turned his attention away from theoretical quantum mechanics and toward K-6 science education following the birth of seven children. Beginning in 1959, Karplus received NSF support to develop the Science Curriculum Improvement Study (SCIS) which was a hands-on, laboratory-based program that employed an investigate-formalize-explore learning cycle. (Dykstra,2010; Fuller,2002) In the 70s Karplus would introduce Piagetian ideas to the college level faculty attending AAPT meetings and widespread testing of undergraduates would ensue. In the end, many of the national educational reform efforts of the 1950s-1970s failed. This made it clear to the pioneers in PER that a research base was needed for educational progress.(Heller,2010)

Beginning in the 1960s Fred Reif also periodically left his work on superfluids to focus on physics education which he found "analytical yet humanly compelling". (Reif,2010) By 1969 he had published a paper in *Science* magazine entitled "*Science education for non-science students*". (Reif,1969) Arnold Arons left Amherst for the University of Washington in Seattle and started to work with pre-service teachers (1968-1969).(Arons,1998; McDermott,2010) In the 1960s Seymour Papert (MIT Media Lab) starting thinking and talking about how the computer could be used as a tool to transform education. Researchers, including Bruce Sherwood, worked on project PLATO (University of Illinois) and made progress in using computers for this purpose. (Papert,1993; Smith,1976)

### *ii. PER Milestones in the 1970's and 1980's*

As mentioned previously, physics education research began as a field in the 1970s. The 1970s and 1980s are grouped together for this discussion because, as Fig. 1 on publication rates indicates, the field did not grow very quickly at first. It is possible this slow growth was due in part to President Reagan's slashing of funding to education in the 1980s. It is also possible the mechanisms needed for growth were just not yet in place.

Milestones during the first two decades of the field of physics education research fall into several categories. These include establishing hallmark techniques and foci for research, building a knowledge base regarding student learning in physics, development of new curricular materials, establishing self-governance for the community and advocacy efforts undertaken on behalf of the field.

PhD programs in physics education research (housed in a physics departments or strongly tied to a physics department) were established at a number of R-1 universities during the 1970s and 1980s. The first physics PhDs with thesis work in PER were conferred during this time period. (For more discussion of this see the section on PhDs and post-doctorial programs above.) In addition, for the first time, R-1 institutions granted tenure to physics faculty based on their work in PER. The first people to be granted tenure at an R-1 for PER-based work were Lillian McDermott (1976-University of Washington) and D. Zollman (1978-Kansas State University). (McDermott, 2010-1) There would be no additional tenure cases in physics departments of R-1 institutions for the next twenty years until, in 1998, Bob Beichner was awarded tenure at North Carolina State University for his work in PER.

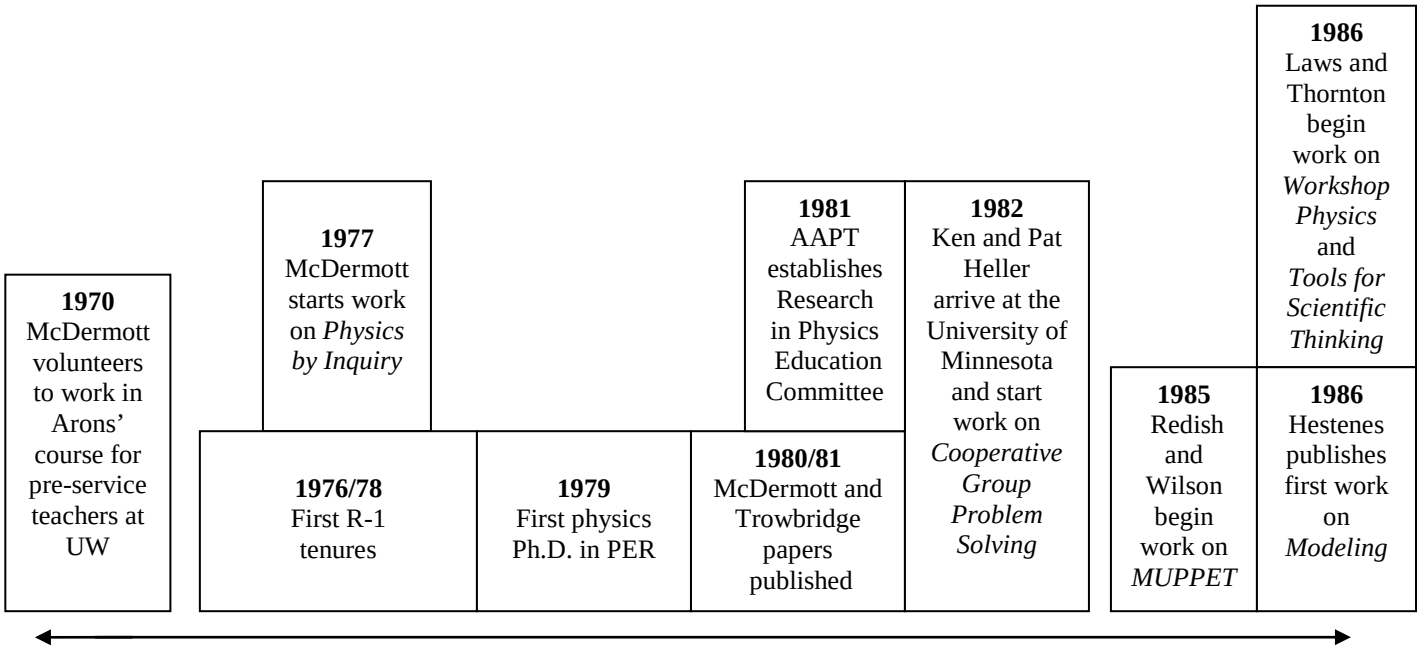


**FIGURE 4**. Key milestones in PER during the 1970's and 1980's.

Nonetheless, the research base in PER expanded significantly during these years. Innovative teaching ideas made their way into the classroom - raising questions of whether specific activities were useful for learning, and how group work affected instruction. In the early 70s, Reif, Karplus, Arons, McDermott, Zollman, Fuller and others started looking at teaching and learning of physics from a scientific perspective. (Arons,1976; McDermott,1974; Reif and Larken,1976; Spears and Zollman,1974). But the 1980s papers documenting careful investigations into student understanding of specific topics by Trowbridge and McDermott are considered especially important. (Trowbridge and McDermott, 1980 and 1981) In addition to discussing specific findings, these papers and others by McDermott articulated a general approach to engaging in PER. The development of the *individual demonstration interview* was adapted from Piaget's clinical interview by the UW Physics Education Group. This methodology used to gather evidence of a student's understanding was so effective that it dominated the field during the early years.

In addition, both McDermott and Reif generally describe taking a scientific approach to science instruction in compelling and articulate ways. Reif and his collaborator, Jill Larkin, additionally contribute to the field during this time through their studies of problem solving. (Reif, 1976) By the early 1980s, Ken and Pat Heller have arrived at the University of Minnesota and begin to develop their pedagogical approach, *Cooperative Group Problem Solving*.(Heller,1992) This work is especially important because it added to both the body of knowledge regarding problem solving in physics and the range of PER based approaches available for adoption.

By the late 1980s a change in focus could be detected as some research groups moved from documenting students' understanding at one or two points in the learning process (usually

pre/post-instruction) to learning process studies looking at how students' understanding evolves over time.

Other PER milestones during this period involved the development of curricular materials that were based on PER findings and had been widely evaluated using PER oriented methodologies. Lillian McDermott and others at the University of Washington began work on the *Physics by Inquiry (PbI)* curriculum in 1977. (McDermott, 2010-1) It was commercially published in 1996.(McDermott,1996) In my opinion, the impact of the specific materials developed for PbI (for example, the units on DC circuits) and the general approach to teaching college level physics through hands-on activities that PbI exemplifies cannot be overstated.

In addition, innovative instructional tools were developed. In 1986, Priscilla Laws (Dickinson College) and Ron Thornton (Tufts University) separately applied to the Department of Education's Fund for Improvement of Post-secondary Education (FIPSE). Priscilla wanted to develop materials that could be used to teach calculus-based introductory physics courses using only activity-based learning (no lectures). Ron wanted to develop curricular materials to support the effective use of new computer-based data collection tools and sensors (known as MBL tools) he had been developing in conjunction with an organization local to Tufts called TERC (formerly called Technologic Education Research Consortium).(TERC, 2010) Although Thornton and Laws did not know one another, the FIPSE project monitor involved required they join forces on the grants. The result was the *Workshop Physics* approach and curriculum as well as the *Tools for Scientific Thinking* curriculum. (Laws,1991; Thornton,1987) Laws and Thornton won the Charles A. Dana Foundation Award for Pioneering Achievements in Education in 1993 for this work. They joined with David Sokoloff soon after their first joint FIPSE grant and the three (Laws, Sokoloff and Thornton) have contributed to the field of PER in many important ways ever since.

Starting in about 1983, Joe Redish's eye begins to wonder from theoretical nuclear physics. By 1986 he receives a FIPSE grant to develop the *Maryland Project on Physics and Educational Technology* or *M.U.P.P.E.T* (Redish,1993) This work will lead to collaborations with Jack Wilson including the *Comprehensive, Unified Physics Learning Environment* (*C.U.P.L.E*). Wilson will later (1992) combine C.U.P.L.E with the work of Laws and Thornton to create the first generation of *Studio Physics* courses at Rensselaer Polytechnic Institute. (Wilson,1994)

Workshops held at AAPT meetings were (and are) an important mechanism for dissemination of findings and approaches. In regard to one such workshop, David Hestenes (Arizona State) writes:

> *"Karplus (with help from Tony Lawson) designed an impressive "Workshop on Physics Teaching" and conducted it at the 1977 AAPT meeting in Anaheim (see Robert Fuller's review). I attended with [my colleague] Tillery, and this stimulated me to join with Tillery in teaching a course on science teaching for elementary school teachers and hiring Tony Lawson. More important, it stimulated me to read all of Piaget's writings and delve into the science education literature, such as it was."*
>
> (Hestenes, 2010)

Both Bob Fuller and Dean Zollman are credited with facilitating the dissemination of important PER work using the existing tradition of workshops at AAPT meetings. Dewey Dykstra describes Bob Fuller as being instrumental in getting the early workshops by Karplus to occur. (Dykstra, 2010) According to the AAPT's statement on the history of the organization:

> *"When he served as AAPT Staff Physicist in 1975-77, Dean Zollman, a persuasive advocate of the workshop as a means of introducing new discoveries and approaches in the physics classroom, was instrumental in the development of the workshop program that has become an important feature of the Summer and Winter Meetings. This program has seen dramatic growth in the past decade. Two types of workshops are offered: AAPT workshops, conducted by AAPT members and sponsored by one of the Area Committees, and commercial workshops, conducted by equipment suppliers for promotion of their products. At the 1977 Winter Meeting, there were 3 AAPT workshops and 8 commercial workshops….. The 1998 Winter Meeting included 26 AAPT workshops and 16 commercial workshops."* (AAPT, 2010)

The AAPT committee on Research in Physics Education (RIPE) was founded as an Ad Hoc committee in 1981. It soon became a standing committee, giving significant structural support to the field. Lillian McDermott was the first chairperson. (McDermott, 2010-1) One result of the formation of RIPE were planned invited and contributed sessions at national AAPT meetings where the audience could hear sequences of talks that focused on physics education research.

### *iii. 1990-1996 Milestones*

1991 to 1996 were important years for the field of PER. A number of "immigrants" (from more traditional sub-disciplines of physics) joined or settled into the field. During this time period several people who were articulate, highly respected and dedicated to the field (Redish, Heller, Hestenes and Mazur, for example, along with the first generation of scholars like McDermott, Zollman and Arons) began to make arguments about why PER is important, and why it should be done in physics departments. The value of their advocacy cannot be overstated.

In addition, new measurement tools and research methods were introduced. The *Force Concept Inventory* (FCI) was published in *The Physics Teacher* in 1992 as a multiple choice assessment tool used to measure students' conceptual understanding of mechanics. (Hestenes,1992) Its impact was enormous. In department after department across the country the same conversations occurred: "This is easy. Maybe their students can't do this but our students can certainly do this." Once the exam was given locally an intellectual struggle ensued as individuals and departments tried to make sense of the dismal outcomes and the associated implications for instruction. (Dykstra,2010; Hestenes,2010 and Reif,2010) Many other similar kinds of tools assessing various topical areas in physics were developed over the next twenty years. The use of video to study groups of students learning in naturalistic settings (usually the classroom) is also introduced to the community.

***1990-1996: The Formative Years***

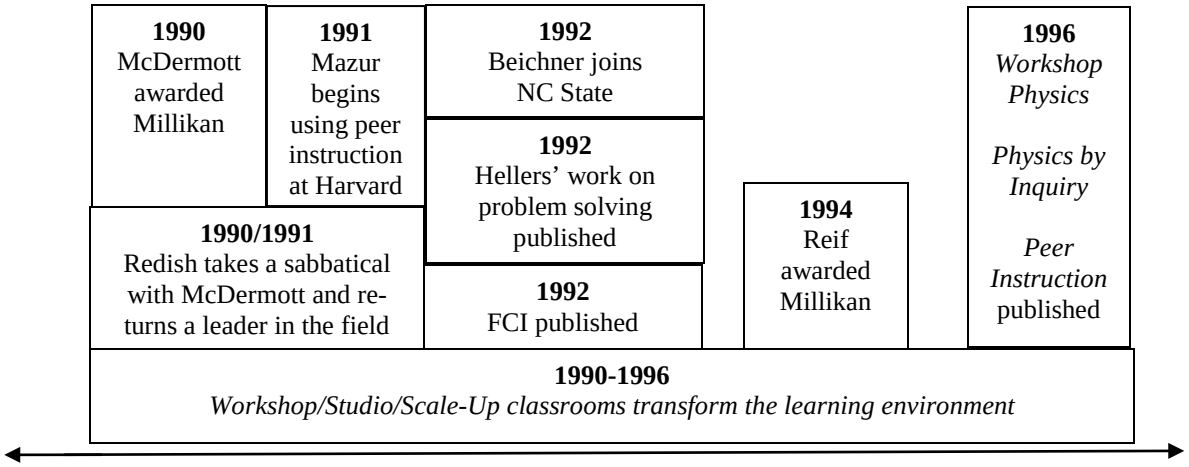


**FIGURE 5.** Key milestones in PER 1990-1996.

In 1990/1991 Joe Redish took a sabbatical with Lillian McDermott at the University of Washington. In many ways, his sabbatical reinvigorated the field. Researchers wanted to look at issues beyond concept formation and this period marked the start of a focus on non-subject matter related course outcomes and student characteristics. This began a focus on epistemological beliefs as a legitimate area of physics education research and the Maryland Physics Expectation Survey was developed to investigate such issues. (Redish,1998) Momentum continued to build for this area of study with David Hammer's dissertation *More than Misconception* in 1996.

The publication of two AJP papers in 1992 moved Ken and Pat Heller's work on problem solving, including their *Cooperative Group Problem Solving* pedagogical approach, to the fore. (Heller,1992-1 and 1992-2) In my opinion, this work was important for two reasons. First, it addressed an area of concern for all physics instructors-quantitative problem solving. Second, it provided an example of how physics education research can be directly applicable to classroom instruction and useful to main stream physics instructors. Similarly, beginning in 1991, Eric Mazur implemented *Peer Instruction* in his courses at Harvard. At about this same point in time Mazur and Jose Mestre also began work to develop the classroom procedures and personal response systems (i.e. the *ClassTalk* system) needed for straightforward implementation of the Peer Instruction technique. (Mazur, 1996, 2001, 2011) Soon Peer Instruction would be the most widely adopted PER based curricular innovation in university level physics courses nationwide. In the mid 1990's, Gregor Novak, Andrew Gavrin, Evelyn Patterson and Wolfgang Christian introduced another popular instructional strategy, *Just in Time Teaching* (*JiTT*). In JiTT, students submit answers to pre-class assignments via the internet. Instructors use these submissions to hone what will be done in class that day, thereby making a better match between current student difficulties and classroom instruction. (Novak, 1999)

In the period from 1990 to 1996, new classroom environments were envisioned and implemented. *Workshop Physics* (along with *MUPPET* and *CUPLE* discussed above) laid the foundation for the *Studio Physics* program Jack Wilson started at Rensselaer Polytechnic Institute in 1993. (Wilson,1994) Studio Physics, in turn, informed the development of the *Scale-Up*

classroom developed by Bob Beichner. These classrooms blur the line between lecture, recitation and laboratory as any one of those actions can occur comfortably within the same classroom space. These new classroom environments encourage coherence between the various aspects of the course which is often lost when lecture is undertaken on a different day, in a different room and often by a different instructor than are laboratory and problem solving practice. *Workshop/Studio/Scale-Up* classrooms facilitate activity-based learning in cooperative groups and make it easy for the professor to choose to do less talking during the class period. Thanks in large part to a willingness on Beichner's part to do the hard work of interacting with others as they worked through local educational reform and classroom remodels, Scale-Up (/studio/workshop) classrooms now exist all over the country (see Fig. 6) and in many institutions outside the United States.

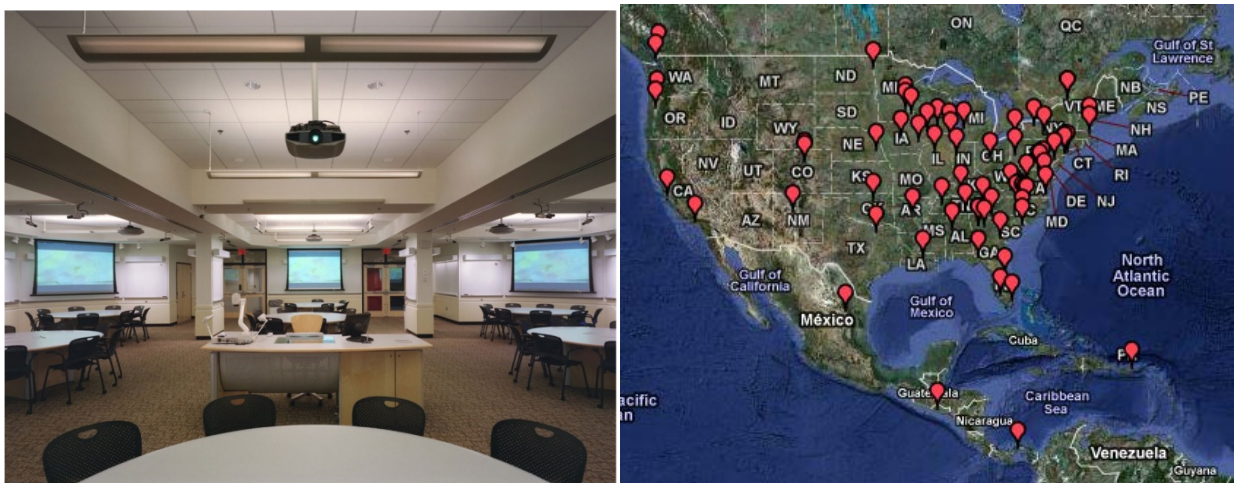


**FIGURE 6.** MIT's Scale-Up style classroom and the location of others like it across the country. (http://www.ncsu.edu/per/scaleup.html)

In 1996, the *Workshop Physics* curriculum that Priscilla Laws had developed was commercially published as were McDermott's *Physics by Inquiry* curriculum and Mazur's book *Peer Instruction*. (Laws,1996; Mazur,1996; McDermott,1996) It wasn't long before the field experienced a significant growth spurt.

Michael Wittman writes:

> *"By the 90s, there was a push by many departments to hire faculty who could improve their local teaching - this interest was fueled in large part by the Great Proselytizers, Lillian McDermott and Eric Mazur….… They gave talks anywhere that would have them, presenting the scientific basis of the field, including the existence and use of simple instruments like the FCI. Such a survey really pushed non-PER faculty to consider whether their students knew what they were supposed to know, and gave them a simple tool to measure things. I think that created just enough pressure in the system to allow for the field to take off…"*
> *(Wittman, 2010-2)*

A cluster of AAPT Millikan Awards were presented to physics education researchers during this period. Lillian McDermott received the award first (1990), followed by Reif (1994) and Redish (1997).

### *iv. Post 1996 Milestones*

In many ways the milestones of the Post-1996 era are the long ripening fruit of the work done in the previous decades. Several people worked from several angles to establish a regular PER conference. This process is described clearly in Beichner's paper *An Introduction to Physics Education Research*. Beichner writes:

> *"There had been a series of meetings that focused on physics education research. One of the first of these was held at North Carolina State University in the fall of 1994. Discussion topics ranged from the types of studies carried out by physics education researchers to the curriculum that PER graduate students needed to see. An outcome of the meeting was a 1995 white paper submitted to NSF by a prominent group of physics education researchers which may have had some influence on NSF's generally positive view of PER. Joe Redish believes the white paper contributed to him securing funding for the International Conference on Physics Education (ICPE), which was held at Maryland just before the American Association of Physics Teachers (AAPT) summer meeting in 1996. Between the ICUPE and AAPT meetings there was an "Interval Day" meeting where approximately 75 people discussed what was needed to advance the PER field. It was decided that Redish would pursue additional publication space and Dean Zollmann would attempt to create a piggy-back conference for the next AAPT summer meeting. Since 1997 there has been such a conference (called PERC) held every summer" (*Beichner, 2009)

One nagging area of concern for physics education researchers was a narrow publication pipeline. This issue was largely addressed when, between 1999 and 2005, several new publication venues became available. In 1999, a physics education research section (PERS) with separate editor (Joe Redish was the first) was added to the *American Journal of Physics*. In 2001, a peer-reviewed proceedings was introduced for the annual physics education research conference (Karen Cummings, Jeffrey Marx and Scott Franklin founding editors). In 2003 those proceedings became an American Institute of Physics (AIP) publication. Most notably however was Bob Beichner's establishment of *Physical Review Special Topics-Physics Education Research* in 2005. The respectability of the *Physical Review* name made a significant difference in how PER publications were viewed by promotion and tenure committees, especially at R-1 institutions.

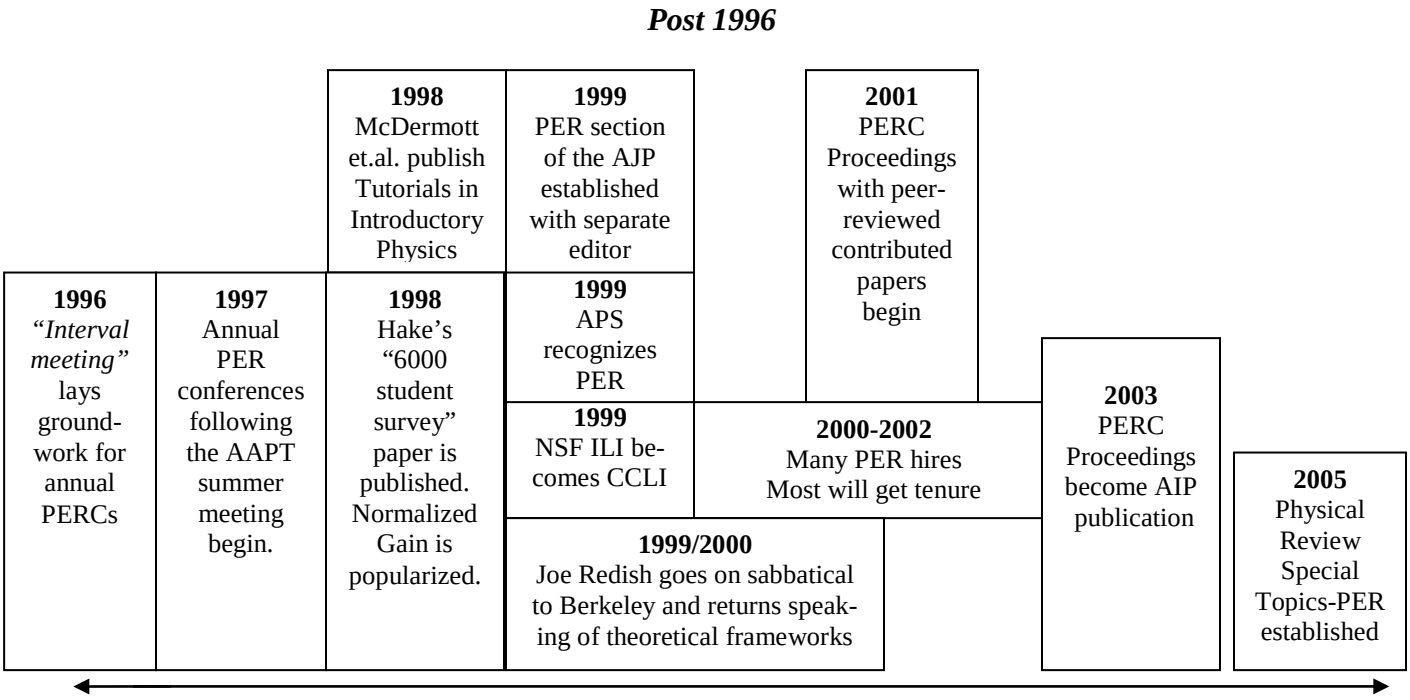


**FIGURE 7.** Key milestones in PER 1996 to present.

Many people continued to work tirelessly to disseminate PER materials and findings. Lillian McDermott and the Physics Education Research group at the University of Washington have run summer professional development workshops (including at the national AAPT meetings) of one kind or another since the early 1970s. (McDermott, 2010) Ken and Pat Heller, Priscilla Laws, Ron Thornton, David Sokoloff and David Hestenes (among others) have, in total, offered hundreds of workshops that introduce secondary and post-secondary faculty to PER based materials and methods. The *New Physics and Astronomy Faculty Workshops*, established in 1996, are another very important mechanism by which PER findings are shared. Eric Mazur has given an extraordinary number of talks on the topic of Peer Instruction and PER.

In 1998, Richard Hake published his paper entitled " Interactive-engagement vs traditional methods: A six thousand-student survey of mechanics test data for introductory physics courses". This paper not only formally introduces the PER community to normalized gain as a metric for student learning. It also makes a clear case with compelling quantitative evidence that interactive teaching strategies can improve conceptual learning outcomes beyond what is typically measured in more lecture-based classroom environments. (Hake, 1998)

The post-1996 era is also one of growing recognition of the value of the field. Lillian McDermott et. al. published *Tutorials in Introductory Physics* in 1998 and this made it easier for many physics professors to imagine implementing PER based materials in university level physics courses for scientists and engineers. (McDermott, 2001) In 1999, physics education research was officially accepted by the APS as a reasonable field of study for scholars in physics departments (statement 99:2). (APS, 2010) There were a significant number of students who graduated with PER based PhDs during the years 2000-2002 and most had no difficulty finding a job. Many went directly into tenure track positions, some at R-1 institutions. By about 2008 the vast

majority of these individuals had been awarded tenure for their PER based work. (Wittman, 2010-2)

Physics education research interests continue to broaden with, for example, an increased interest in knowledge structures (for example, Andy DiSessa's *Knowledge in Pieces* (1988) paper). A push is being made for grounding empirical research in theory, with a strong contribution from DiSessa's group at Berkeley, Hammer and Redish's group at Maryland (Hammer is now at Tufts) and the group at Ohio State (Boa et al.). (Redish took a sabbatical in Berkley during 1999-2000).

With the transition of the NSF's Improving Laboratory Instruction (ILI) program to the Course, Curriculum and Laboratory Improvement (CCLI) program in 1999 and in 2010 to the Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (TUES) the NSF begins to state that education grant proposals needed a research justification (or at least discussion). In addition, the NSF now funds PER directly rather than just through curriculum development projects. Discipline based educational research (DBER) is an option for the topic of study on NSF fellowship applications.

## III. CONCLUDING COMMENTS

This paper was written as part of the *Status, Contributions, and Future Directions of Discipline Based Education (DBER) Research* project undertaken by the Board on Science Education at the National Research Council/National Academies. In addition to authoring this paper I also participated in a meeting in October of 2010 at which I shared an overview of this history with the board. Representatives from the astronomy, biology, chemistry, engineering and geosciences education research communities shared equivalent histories of their research fields.

My impression from the presentations that I heard was that there are several striking differences between the history and status of the PER community and that of our sister communities. The differences that I noted extend well beyond the fact that PER has the longest history, and is, in many ways and by far, the most developed of the DBER fields. Perhaps the most notable difference to me was the fact that PER is very much undertaken in physics departments by physics faculty. Our PhDs are predominately physics PhDs. Neither of these characteristics seemed to be shared by many other DBER communities. The fact that our PhDs tend to come out of physics departments, paired with the fact that the number of PER programs in PhD granting institutions is quite small (less than 10) makes the PER PhD pipeline feel fragile to me in comparison to other disciplines. On the other hand, PER still has post-graduates (often faculty level professionals) who migrate into the field from other areas of physics research. This appears to be very rare now in other disciplines. Perhaps these characteristics are all related. Regardless, I believe that they are the result of conscience choices made by leaders in the PER community throughout its history. I personally think that the PER community made wise choices. We are a more effective community because of our significant presence in physics departments.

The differences that I note above indicate to me that the political, logistical and PhD pipeline issues faced by the PER community are largely reduced or differ in significant ways in other DBER fields. My conclusion is that while we may be able leverage common interests in the larger DBER community when it comes to our research agenda, other issues facing the PER community will be ours to address alone.

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