A Brief History of Research on Preparation of Physics Teachers

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Outline

1. Some general issues related to research on teacher preparation

2. Some findings of studies on specific issues

3. Brief reviews of various preservice and inservice programs

Motivation

- APS and AAPT are attempting to improve the preparation of physics teachers
  - Physics Teacher Education Coalition (PhysTEC)
  - PTEC
  - National Task Force for the Professional Preparation of Teachers of Physics

So…how do you do it?

Question: What does the research say?

Answer: Many different things…

Teacher Preparation: Research vs. Practice

- Efforts to improve teacher preparation are treated as practical, applied problems incorporating “art and design”
- Focus is on overall program change, not on close examination of individual program elements
- Assessment and evaluation—such as there is—tends to be on broad program measures

“Practical” Approach to Course and Program Development

- Multiple elements of courses or programs are simultaneously introduced or revised
  - Revisions are based on practical experience, interpretations of the literature, plausible hypotheses, etc.
  - Revisions tend to be ongoing, and mutually influencing
- Documentation of changes in practice or outcomes is often haphazard or superficial

Scholarly Approach

- Acknowledge any ambiguous and/or conflicting evidence
- Make substantive reference to relevant published work
- Claims implying broad validity in many instructional contexts should be accompanied by particularly strong evidence

Presentation of Data

- Are actual diagnostic instruments provided?
- Are data tabulated so as to allow readers to interpret and analyze directly?
- Are categorizations which are employed reasonable, logical, clear, and distinct?

Useful Presentation of Data

- Detailed descriptions of instructional activities
  - Student tasks and methods for accomplishing those tasks
  - Instructor's role
- Samples of curricular materials (including graphics, photos, etc.)
- Description of evolution of activities, motivations for changes

Discussion of Practices

- Descriptive and enumerative:
  - "we did this…"
  - "students take these courses…"

Versus:

- Systematic, analytical, and reflective:
  - "we did this *because*…"
  - "the general theme of these activities is…"
  - "these courses and activities are sequenced so as to achieve this goal…"
  - "In retrospect, the choices we made were…"

Elements of Evaluation

- Objectives
  - What one is trying to do
- Benchmarks
  - Indicators of whether one has achieved the objectives
- Outcomes
  - Evidence and analysis that demonstrates how closely benchmarks have been approached

Research, Broadly Defined

1. A question is posed to which an answer is desired

2. A systematic investigation is launched in an effort to answer the question

3. Potential answers are carefully scrutinized

Nature of Evidence

- Systematic observations
  - Incorporate pre-planning
  - Accompanied by retrospective review
  - Situate any particular observation within the full range of related observations

Versus:

- Anecdotes
  - Illustrations of phenomena or events
  - Relative frequency of occurrence, and degree of representativeness, are *uncertain*

Other Forms of Investigation

- Case Studies
  - extremely small sample sizes, ≈ 1
  - may provide insight, generate hypotheses
  - lacking additional data, generalizability is highly uncertain
- Personal Reflections
  - sample size = 1
  - explicitly subjective
  - may be profound, true, and valuable
  - validity difficult to determine

Usefulness of "Non-Research"

- "How-to" discussions based on extensive personal experiences may be very valuable and offer great insights to other practitioners
  - Can provide starting points for reflecting on and revising current practice
  - Can provide basis for testable hypotheses
- Rigorous testing may be difficult or inappropriate

Some Important Distinctions

- “Didactical analysis” [“theory”] vs. empirical research [“experiment”]
- Evaluation Report vs. Peer-reviewed research
- Prospective (“preservice”) vs. Practicing (“inservice”) teachers
  - [teacher preparation vs. professional development]
- Research on preparation of “science” teachers vs. preparation of “physics” teachers

More Important Distinctions

- Preparation of *elementary* teachers vs. preparation of *high-school* teachers
- Assessment of courses which *include* pre-service teachers vs. courses which *target* preservice teachers
- Research *outside* U.S. vs. *inside* U.S.
- “Pre-bac” vs. “post-bac” preservice teachers

Assessment of Pedagogical Content Knowledge

"*Pedagogical Content Knowledge*" (PCK):

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.

- *“Pedagogical Content Knowledge”* (Shulman, 1986): Knowledge needed to teach a *specific topic* effectively, beyond general knowledge of content and teaching methods

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  “…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…”

Assessment of Pedagogical Content Knowledge

- No currently accepted, standard physics-PCK instruments exist
- Those instruments under development (e.g. by Seattle Pacific U., U. Maine, and U. Colorado) incorporate analysis of student-teachers' interpretations of problem responses by, or of discussions among hypothetical students
- Documentation (not assessment) of PCK by Monash (Australia) group (e.g., Loughran, Mulhall, and Berry, JRST, 2004)

Loughran, Milroy, Berry, Gunstone, and Mulhall (2001); Loughran, Mulhall, and Berry (2004); Loughran, Berry, and Mulhall (2006)

- Described method of documenting science teachers' PCK
- A topic is chosen (e.g., "Forces" or "Electric Circuits") and teachers collaborate to generate 5-10 "Big Ideas" for the specific topic (e.g., "The net force on a stationary object is zero").
- Teachers then collaborate to provide responses to a set of 8 items for each of the Big Ideas
- Teachers provide an accompanying narrative to explain their responses

1. What you intend the *students* to learn about this idea
2. Why it is important for students to know this
3. What else *you* know about this idea (that you do not intend students to know yet)
4. Difficulties/limitations connected with teaching this idea
5. Knowledge about students' thinking which influences your teaching of this idea
6. Other factors that influence your teaching of this idea
7. Teaching procedures/strategies (and particular reasons for using these to engage with this idea)
8. Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)

Other Work on Physics PCK

Halim and Meerah (2002)

- Interviews with 12 post-graduate teacher trainers in Malaysia
- Teachers asked to give answers to several physics questions, and to provide predictions of how students would answer
- Teachers asked how they would teach the student to understand the teachers' answer
- *Finding:* Some teachers were not aware of students' ideas and, of those who were, many did not address those ideas through their teaching strategies

Other Work on Physics PCK

Galili and Lehavi (2006)

- 75 Israeli high-school physics teachers responded to a questionnaire
- They were asked to provide definitions of physics concepts, and “to express their opinions as to the importance of concept definitions in teaching and learning physics”
- Although nearly all teachers said that mastering concept definitions was important in physics teaching, almost none of them provided operational definitions for the various concepts

Other Work on Physics PCK

Sperandeo-Mineo, Fazio, and Tarantino (2005)

- 28 prospective Italian physics teachers (math graduates), probed near beginning of graduate teaching program
- Initial program workshops said to bring about improvements in their PCK regarding teaching of heat and temperature topics

Teacher Preparation Programs with Explicit Focus on PCK

Etkina (2005)

- Masters + certification program
- Six core physics course with emphasis on PCK
- Example: *Teaching Physical Science*
  - students learn content using diverse curricula
  - students design and teach curriculum unit
  - students are examined on methods for teaching and assessing student learning of specific physics topics

Teacher Preparation Programs with Explicit Focus on PCK

Wittmann and Thompson (2008)

- Two courses, part of Masters program in Science Teaching
- Learning of physics content using research-based curricula
- Analysis and discussion of curricular materials and related research papers
- Students “gain insight into how students think about physics through education research”
- Data indicate significant improvements in performance on conceptual diagnostic questions

Teachers’ Knowledge of Students’ Ideas

Berg and Brouwer (1991)

Canadian high-school physics teachers gave predictions of students’ responses on conceptual questions

- Trajectory of ball rotated in circle
- Trajectory of wrench dropped on moon
- Total force on ball thrown upward

- Teachers predicted much higher correct-response rates than those actually observed:
  - *Rotating ball:* teachers’ prediction, 36%; students, 19%
  - *Wrench on moon:* teachers’ prediction, 74%; students, 29%
- Teachers underestimated popularity of alternative conceptions
  - Total force on ball is upward on way up with no force at top of path
  - Teachers’ prediction: 33%; Students: 56%

Early History

- Summer workshops for inservice physics teachers began in the 1940s
- Initially supported by private industry
- NSF support began in early 1950s
- Rapid expansion in funding beginning in 1956, explosion in funding starting in 1957
- PSSC curriculum developed and disseminated beginning in 1958-1960

Olsen and Waite (1955)

- Evaluation of eight years of six-week summer institutes for physics teachers (50 per summer) sponsored by General Electric Corporation, held at Case Institute of Technology
- Questionnaires received from 60% of all former participants
- 50% of these report improved attitude or enthusiasm
- Dramatic increase in enrollment at Case of students of these institute participants (0→45), with above-average scores on pre-engineering “ability test”

Physical Science Study Committee

Donohue (1993)

- During the summer of 1958, five teacher institutes trained 300 physics teachers in the use of the new [PSSC] curriculum. During the 1958-59 academic year, nearly 300 schools and 12,500 students used the experimental new curriculum; in 1959-60, almost 600 schools and 25,000 students in thirty-one states and the District of Columbia used it.

Finlay (1962)

- As of October, 1961, a conservative approximation of the number using the [PSSC] course in 1961-62 was 1800 teachers and 72,000 students; Most users felt it was pitched at an appropriate level, a minority felt it was too advanced.

French (1986)

- Over 100,000 students using PSSC by late 1960s.

NSF Summer In-Service Institutes

Maxwell (1967)

- 1959-1966: avg. 23 physics institutes per year (approx. 7% of total)
- In 1965, 22-71 participants accepted to 30 summer institutes; about 1/3 PSSC
- Many “multiple field” or “general science” institutes also offered physics

Heller, Hobbie, and Jones (1986)

- NSF Summer in-service workshop in Minnesota; 5 weeks workshop + 4 week industrial experience; selective admission; Participants enjoyed and valued it; logistical issues discussed

Lippert, Heller, Jones, and Hobbie (1988)

- Follow-up to previous study; 20-page questionnaire to 14 participants, + interviews with four
  - 76% included more modern physics topics in their teaching
  - 65% made explicit comments about implementing a more conceptual approach in their classroom
  - 64% implemented new student experiments
  - Dramatic shift away from heavy (80%) lecturing: 61% → 3%
  - 42% reported increases in enrollment

McDermott (1974)

- Inquiry-based lab-centered combined course for preservice elementary and secondary teachers; topics in PSSC and Project Physics [Progenitor of *Physics by Inquiry*]

McDermott (1975)

- Recommendations for high-school physics teachers:
  - understand basic concepts in depth
  - be able to relate physics to real world

  Become familiar with:

  - phenomenological basis for physics knowledge
  - inquiry-based, laboratory-centered learning
  - physics as part of general culture
  - good programs (e.g. PSSC, Project Physics)
  - learning theory (Piaget, need for concrete experiences)
  - skills for inquiry/hypothesizing/designing experiments/communicating

McDermott (1990)

- Need for special science courses for teachers; description of pre-service secondary program

McDermott (2006)

- Preparing K-12 teachers in physics: review and reflections of 30 years of experience in teacher preparation

McDermott, Heron, Shaffer, and Stetzer (2006)

- Document content-knowledge inadequacies (relative to intended teaching topics) among preservice high-school teachers
- Document dramatic learning gains of both preservice teachers and 9th-grade students of experienced in-service teachers following use of *Physics by Inquiry* (PbI) on light and apertures.
- Reference to many other consistent, documented reports of significant learning gains through use of PbI-related materials, Tutorials, etc.

Oberem and Jasien (2004)

- NSF-funded three-week summer inservice course for high-school teachers
- Most taught biology and physical science
- No lectures; hands-on, lab-based, inquiry oriented, uses *Physics by Inquiry*
- Three years of data; normalized gain ($N \approx 33$) 0.38-0.74 on conceptual questions (TUG-K, CSEM, etc.) in heat and temperature, kinematics, electric circuits, light and optics, electrostatics, and magnetism
- Delayed gain, six to eight months later: heat and temperature, 0.41 (from 0.38); EC 0.63 (from 0.73), electrostatics 0.26 (from 0.45); ($N \approx 22$)

Nanes and Jewett (1994)

- Four-week summer inservice institutes
- Includes lesson preparation and presentation, academic-year activities (six televised video conferences plus three day-long topical conferences plus site visits)
- 40 crossover physics teachers, very diverse in preparation
- Normalized gains on content tests: 40-73%
- Post-institute interviews, large and sustained increase in confidence, teach more modern physics topics

Huffman, Goldberg, and Michlin (2003); Huffman (2007)

- Evaluations of CPU (Constructing Physics Understanding) Project
- 100-hr workshops, two weeks summer + following school year
- Workshop leaders included high-school physics teachers
- Inquiry-based investigative activities centered around computer simulations
- Site visits, interviews; FCI, similar amounts of time on force and motion
- *Findings:* significantly higher FCI scores in both new-user and lead-teacher classes compared to traditional class; surveys indicated various standards-recommended activities were used more often by CPU classes

Hestenes, Wells, and Swackhamer (1992); Wells, Hestenes, and Swackhamer (1995); Hake (1998)

- Description and assessments of “Modeling Method” of instruction
- Organizes course content around small number of basic models such as “harmonic oscillator” or “particle with constant acceleration”
- Students carry out qualitative analysis using multiple representations, group problem-solving, and inquiry-style experiments followed by intensive and lengthy inter-group discussion using “white-boarding”
- *Outcome:* much higher learning gains on FCI and MBT for high-school classes taught with Modeling method, compared to traditional; also, better performance on more traditional quantitative problems (from NSTA and PSSC)

Halloun and Hestenes (1987); Vesenka and Beach (2002)

- Studies showing improved learning gain in college courses using Modeling method

Andrews, Oliver, and Vesenka (2003)

- Three-week summer institute in California using Modeling method; combined pre- and in-service teachers; high normalized gains on TUG-K (0.35) and FCI (0.43) for 18 undergraduate pre-service students

Vesenka (2005)

- Normalized gains on TUG-K ≈ 60% (N = 63; three years combined) after two-week workshop for in-service teachers using Modeling Instruction.

Otero, Finkelstein, McCray, and Pollock (2006)

- Report on Colorado “Learning Assistant” program, all sciences combined.
- High-performing undergraduate students employed as instructional assistants in introductory science courses
- Two weekly meetings to prepare and review learning activities + one-semester course on Math/Science teaching
- Increased teacher recruitment
- Improved content knowledge of students in classes that use LAs, valued by faculty instructors

Mestre (2000)

- Description of course, titled “Motion, Interactions and Conservation Laws: An Active-Learning Approach to Physics,” specifically designed for undergraduates
- Enrolls graduates and inservice teachers interested in secondary physical science
- Participants work with the NSF-funded “Minds-On Physics” high school curriculum materials, in an activity-based mode to examine various topics in mechanics and related areas

Jasien and Oberem (2002)

- In-service summer physics course in California
- 30-60% incorrect pretest responses on basic questions about heat, temperature, specific heat, internal energy

Long, Teates, and Zweifel (1992)

- 31 participants in two-year summer program (8 wks/6 wks) in Virginia
- high participant satisfaction
- Report deeper coverage of concepts in their classes
- Increases in use of labs, demos, computers

MacIsaac, Zawicki, Henry, Beery, and Falconer (2004)

- Alternative certification, post-bac Masters program in New York
- Summer and evening courses + intensive mentored teaching
- High demand for program; selective admission

Novodvorsky, Talanquer, Tomanek, Slater (2002)

- Description of preservice physics teacher program at University of Arizona
- Contained entirely within College of Science.

Kagan and Gaffney (2003)

- Description of bachelor's degree program in physics department with revised requirements
- Fewer upper-level physics courses, instead choose from courses in other sciences plus teaching internship
- *Outcome:* Substantial number of graduates of new degree program (≈ 50% of traditional grad rate) over and above number of grads in traditional degree program

Summary

- Many programmatic evaluations have been reported
- Relatively few studies of individual elements of programs or courses have been reported
- Great potential lies in future research regarding preservice physics teachers' PCK