

Research on Physics Learning and Research-Based Instructional Strategies

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Probably, one of the most significant truths learned through our recent [physics] testing programs, is the failure of students to accomplish any large fraction of the supposed requirements of courses pursued. In other words, what the teacher thinks he is teaching is usually many times what he actually teaches.

[A. W. Hurd, "Achievements of students in physics,"
Science Education **14**, 437 (1930)]

Outline

- What is physics education research (PER)?
- How is PER connected to developments in physics instruction?

Physics Education As a Research Problem

Within the past 40 years, physicists have begun to treat the teaching and learning of physics as a research problem

- Systematic observation and data collection; reproducible experiments
- Identification and control of variables
- In-depth probing and analysis of students' thinking

Physics Education Research (“PER”)

Goals of PER

- Improve effectiveness and efficiency of physics instruction
 - guide students to learn concepts in greater depth
- Develop instructional methods and materials that address obstacles which impede learning
- Critically assess and refine instructional innovations

U.S. Physics Education Research (PER) Has Always Been Linked to Physics Instruction ...

So, to understand the history of PER, we must review developments in physics instruction...

*[Reference: D. E. Meltzer and V. K. Otero, "A brief history of physics education in the United States," Am. J. Phys. **83**, 447 (2015)]*

Physics Pedagogy Overview: 1860-1970

- Early physics educators advocated instruction based on hands-on investigation and discovery
however...
- Introductory physics instruction increasingly emphasized rote problem solving and execution of prescribed labs
- In the 1960s, physicists attempted to return to original instructional goals, emphasizing authentic laboratory investigations and deep conceptual understanding
- In the 1970s, physicists initiated systematic research to support instructional reforms at the college level, building on pedagogical reforms of the 1960s

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Physics Teaching in the 1880s

Nationwide surveys of high-school and college physics teachers in 1880* and 1884** revealed:

- Rapid expansion in use of laboratory instruction
- Strong support of “inductive method” of instruction in which experiment precedes explicit statement of principles and laws

*F.W. Clarke, *A Report on the Teaching of Chemistry and Physics in the United States*, Circulars of Information No. 6, Bureau of Education (1880)

**C.K. Wead, *Aims and Methods of the Teaching of Physics*, Circulars of Information No. 7, Bureau of Education (1884).

First U.S. “Active-Learning” Physics Textbook:

Alfred P. Gage, *A Textbook of the Elements of Physics for High Schools and Academies* (Ginn, Boston, 1882).

“The book which is the most conspicuous example now in the market of this inductive method is Gage's. Here, although the principles and laws are stated, the experiments have preceded them;

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“The book which is the most conspicuous example now in the market of this inductive method is Gage's. Here, although the principles and laws are stated, the experiments have preceded them; many questions are asked in connection with the experiments that tend to make the student active, not passive, and allow him to think for himself before the answer is given, if it is given at all.”

C.K. Wead,
Aims and Methods of the Teaching of Physics (1884), p. 120.

A TEXT-BOOK

OR THE

ELEMENTS OF PHYSICS

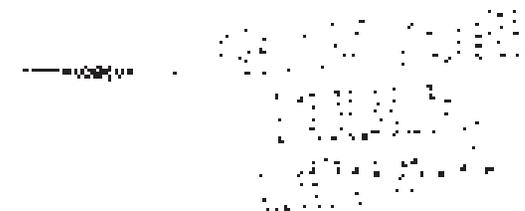
FOR

HIGH SCHOOLS AND ACADEMIES.

BY

ALFRED P. GAGE, A.M.

LECTURER IN PHYSICS IN THE MICHIGAN STATE NORMAL, EAST LANSING, MICH.



BOSTON:

PUBLISHED BY GINN, HEATH, & CO.

1882.

Why Teach Physics? The Views of Robert Millikan

“...the material with which [physics] deals is almost wholly available to the student *at first hand*, so that in it he can be taught to observe, and to begin to interpret *for himself* the world in which he lives, instead of merely memorizing text-book facts, and someone else's formulations of so-called laws...the main object of the course in physics is to teach the student to *begin to think for himself*...”

[R. A. Millikan, Sch. Sci. and Math. **9**, 162-167 (1909)]

Why Teach Physics? The Views of Edwin Hall

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“...physics is peculiar among the natural sciences in presenting in its quantitative aspect a large number of perfectly definite, comparatively simple, problems, not beyond the understanding or physical capacity of young pupils. With such problems the method of discovery can be followed sincerely and profitably.”

[E.H. Hall, 1902]

[in *The Teaching of Chemistry and Physics in the Secondary School*,
by A. Smith and E. H. Hall, 1902, p. 277]

How to Teach Physics: The Views of Edwin Hall

“...It is hard to imagine any disposition of mind less scientific than that of one who undertakes an experiment knowing the result to be expected from it and prepared to work so long, and only so long, as may be necessary to attain this result...”

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[Smith and Hall, 1902, pp. 278]

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Instructional Developments, 1950s-1960s

Revival of the “Inductive” Method

- *At elementary level [around 1962]:* Proliferation of active-learning curricula; intense involvement by some leading physicists
- *At high-school level:* Physical Science Study Committee (PSSC; 1956): massive, well-funded collaboration of leading physicists to develop and test new curricular materials; emphasis on reasoning from evidence; incorporated challenging lab investigations
- *At university level:* hundreds of inservice programs for high-school teachers; Arnold Arons begins development of inquiry-based introductory college course (~1955)

Arnold Arons, Amherst College, 1950s:
Independently developed new, active-learning
approach to calculus-based physics

“Structure, methods, and objectives of the required
freshman calculus-physics course at Amherst College,”
A. B. Arons, *Am. J. Phys.* **27**, 658–666 (1959).

“Definition of intellectual objectives in a physical science course for preservice elementary teachers,” A. Arons and J. Smith, *Sci. Educ.* **58**, 391–400 (1974).

- Instructional staff for the course were explicitly trained and encouraged to conduct “Socratic dialogues” with students.
- Utilized teaching strategies directed at improving students’ reasoning skills.

The Various Language: An Inquiry Approach to the Physical Sciences, A. Arons (Oxford University Press, New York, 1977).

A hybrid text and activity guide for a college-level course; provides extensive questions, hints, and prompts: A model for future “inquiry-based” instructional approaches

Timeline: Research on Learning in Physics

- 1880-1920: ferment in U.S. physics education community regarding instructional methods, but little pedagogical research
- 1920s-1930s: some statistical studies of “reformed” high school physics curricula, and probes of high school students’ reasoning
- 1960s: some physicists led systematic studies of students’ formal reasoning abilities (both K-12 and college-level)
- 1970s: university-based physicists began systematic investigations of physics learning at university level

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- Assess learning through measures derived from pre- and post-instruction testing

Role of Researchers in Physics Education

- Carry out in-depth investigations of student thinking in physics
 - provide basis for “pedagogical content knowledge”
- Develop and assess courses and curricula:
 - for introductory and advanced undergraduate courses
 - for physics teacher preparation

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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...”

Research on Student Learning in Physics: Some Key Results

- Students' *topic-specific* conceptual difficulties often form significant obstacles to learning;
- Inadequate *organization* of students' knowledge often plays a key role.
 - need to improve linking and accessibility of ideas
- Students' *beliefs and practices* regarding learning of physics should be addressed.
 - need to stress reasoning instead of memorization

Beginning of Systematic Research on Students' Ideas in Physical Science: 1970s

- ***School Science:*** R. Driver and J. Easley (1973; 1978) began to systemize work on K-12 students' ideas in science
- ***University Physics:*** In the early 1970s, L. McDermott (U. Washington) and F. Reif (U. California) initiated detailed investigations of U.S. physics students' reasoning at the university level; similar work was begun around the same time by L. Viennot (U. Paris VII) and her collaborators in France.

Initial Development of Research-based Curricula

- ***University of Washington, 1970s:*** initial development of *Physics by Inquiry* for use in college classrooms: worksheets to guide lab activities and problem solving with emphasis on development of physical reasoning; “eliciting” and “resolving” specific student difficulties
- ***R. Karplus and collaborators, 1975:*** development of *Workshop on Physics Teaching and the Development of Reasoning*, directed at both high-school and college teachers: emphasis on development of [“Piagetian”] scientific reasoning skills and the “learning cycle” of guided inquiry.

Frederick Reif, 1970s:

Research on Learning of University Physics Students

[Reif, Larkin, and Brackett, Am. J. Phys. 44, 212 (1976)]

Students' problem-solving behavior investigated through:

- observations of student groups engaged in problem-solving tasks in physics
- “think-aloud” problem-solving interviews with individual students
- analysis of written responses to physics problems.

Lillian McDermott, 1970s:

Development of Research-Based Curricula

[Trowbridge and McDermott, Am. J. Phys. 48, 1020–1028 (1980)]

- Primary data sources were “individual demonstration interviews” in which students were provided with simple physical apparatus and asked to respond to a sequence of questions related to phenomena that were observed.
- Curricular materials were designed to address specific difficulties identified in the research; students were guided to confront directly and then to resolve confusion related to the physics concepts.

David Hestenes and Ibrahim Halloun, 1980s: Systematic Investigation of Students' Ideas about Forces

[Halloun and Hestenes, Am. J. Phys. 53, 1043–1055 (1985)]

Initial development and administration of a research-based test of student understanding [*“Force Concept Inventory”*] revealed the ineffectiveness of traditional instruction in altering college physics students' mistaken ideas about Newtonian mechanics.

Alan Van Heuvelen, 1991:

Use of Multiple Representations in Structured Problem Solving

[Van Heuvelen, Am. J. Phys. 59, 891–897; 898-907 (1991)]

Development of active-learning instruction in physics with a particular emphasis on the need for qualitative analysis and hierarchical organization of knowledge; promoted use of multiple representations such as graphs, diagrams, and verbal and mathematical descriptions.

Ronald Thornton, David Sokoloff, and Priscilla Laws: Adoption of Technological Tools for Active-Learning Instruction

[Thornton, Phys. Educ. **22**, 230–238 (1987); Thornton and Sokoloff, Am. J. Phys. **58**, 858–867 (1990); Laws, Phys. Today **44**(12), 24–31 (1991)]

Discusses potential for improving students' understanding of physics concepts and graphical representations using microcomputer-based instructional curricula.

Comprehensive Review of Research-Based Instructional Methods:

David E. Meltzer and Ronald K. Thornton, "Resource Letter ALIP-1: Active-Learning Instruction in Physics," *Am. J. Phys.* **80**(6), 479-496 (2012).

Definition for “Research-based Active-Learning Instructional Methods in Physics”

[often known as “Interactive Engagement” after R. R. Hake:]

Definition for “Research-based Active-Learning Instructional Methods in Physics”

- 1) explicitly based on research in the learning and teaching of physics;
- 2) incorporate classroom and/or laboratory activities that require all students to express their thinking through speaking, writing, or other actions that go beyond listening and the copying of notes, or execution of prescribed procedures;
- 3) tested repeatedly in actual classroom settings and have yielded objective evidence of improved student learning.

Common Characteristics:

A. Instruction is informed and explicitly guided by research regarding students' pre-instruction knowledge state and learning trajectory, including:

- *Specific learning difficulties related to particular physics concepts*
- *Specific ideas and knowledge elements that are potentially productive and useful*
- *Students' beliefs about what they need to do in order to learn*
- *Specific learning behaviors*
- *General reasoning processes*

- B. Specific student ideas are elicited and addressed.
- C. Students are encouraged to “figure things out for themselves.”
- D. Students engage in a variety of problem-solving activities during class time.
- E. Students express their reasoning explicitly.
- F. Students often work together in small groups.

- G. Students receive rapid feedback in the course of their investigative or problem-solving activity.
- H. Qualitative reasoning and conceptual thinking are emphasized.
- I. Problems are posed in a wide variety of contexts and representations.
- J. Instruction frequently incorporates use of actual physical systems in problem solving.

- K. Instruction recognizes the need to reflect on one's own problem-solving practice.
- L. Instruction emphasizes linking of concepts into well-organized hierarchical structures.
- M. Instruction integrates both appropriate content (based on knowledge of students' thinking) and appropriate behaviors (requiring active student engagement).

Guiding by Inquiry

- Students explore concepts through process of investigation and discussion.
- Students are asked to offer hypotheses or predictions regarding the outcome of investigations.
- Instructors ask students questions—or guide students to ask their own questions—rather than provide either direct answers or detailed formulations of generalized principles.
- Carefully structured question or activity sequences are often used to guide this process...**developed through research...**

Summary

- Systematic research on student learning in physics has been underway for about 40 years.
- Numerous research-based curricula have been developed and tested, and shown to be effective.
- Research-based instructional methods bear many strong resemblances to practices endorsed by early physics educators.