

Physics Education Research: A personal historic overview

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*with the help of
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PER-Φ/E*

* Refers to physics education research done by physicists (Φ) and education specialists (E)

- Key idea: Learning to do science at the professional level — or any complex field — is different from learning broad general skills like reading or arithmetic
 - Content dependence
 - Specialized skills
- Implies that developing an understanding of learning difficulties and creating effective learning environments require substantial input from professionals.
- Throughout its history (since 1980) there have been important contributions from both PER- Φ/E

PER Early History

- Sputnik crisis (1957) raised profile of science education.
- Many scientists began to be involved in educational design (especially for HS)
 - Karplus
 - Arons
 - Reif
 - Zacharias
- PER as a research activity began ~1980.
 - Done by educators, physicists, and cognitive scientists

Some early papers

- Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. *European Journal of Science Education*, 1(2), 205-221.
- diSessa, A. (1980). Momentum flow as an alternative perspective in elementary mechanics. *American Journal of Physics*, 48, 365-369.
- Trowbridge, D. E., McDermott, L. C. (1980). Investigation of student understanding of the concept of velocity in one dimension. *American Journal of Physics*, 48, 1020-1028.
- Champagne, A. B., Klopfer, L. E. , Anderson, J. (1980). Factors influencing the learning of classical mechanics. *American Journal of Physics*, 48, 1074-1079.
- Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and novice performance in solving physics problems. *Science*, 208(4450), 1335-1342.
- McCloskey, M., Caramazza, A. , Green, B. (1980). Curvilinear motion in the absence of external forces: Naive beliefs about the motion of objects. *Science*, 210(5), 1139-1141.

Organizations

- American Educational Research Education
(est 1916)
- National Association for Research in Science
Teaching (1928)
- Cognitive Science Society (1979)
- American Association of Physics Teachers,
Committee for Research in Physics Education
(1980)
- International Society for the Learning Sciences
(2002)

The 1980's

- Student difficulty research, primarily on
 - Mechanics
 - Direct current circuits
 - Geometrical optics
- Early version of Force Concept Inventory (1985)
- Harvard gets on board (1989)

Concepts Research

- Extensive research since about 1980 has demonstrated that in most areas of physics, introductory students show common misunderstandings, even after instruction.
- Standardized concept surveys based on this research began to appear about 1985.
- > 20 such surveys now exist.*

* 17 are included on the resource CD that comes with my *Teaching Physics with the Physics Suite*.

An Example: The Force Concept Inventory (FCI)

- A 30 item multiple choice test to probe student's understanding of basic concepts in mechanics.
- The choice of topics is based on careful thought about what the fundamental issues and concepts are in Newtonian dynamics.
- Uses common speech rather than cueing specific physics principles.
- The distractors (wrong answers) are based on students' common inferences.

**With traditional
instruction
(N=178)**

- Imagine a head-on collision between a large truck and a small compact car. During the collision:

- (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
- (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
- (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
- (D) the truck exerts a force on the car but the car does not exert a force on the truck.
- (E) the truck exerts the same amount of force on the car as the car exerts on the truck.



<u>Pre</u>	<u>Post</u>
70%	46%
3%	1%
1%	0%
1%	2%
26%	51%

The 1990's

- Difficulty research extended to other topics
 - Heat
 - Electrostatics
 - Waves
 - Physical optics
 - Quantum physics
- New topics: the hidden curriculum (MPEX)
- Development of many research-influenced learning environments
- ICUPE, College Park 1996

Concept surveys

Math

- [Mathematical Modeling Conceptual Evaluation](#)
- [Test of Understanding Graphs -- Kinematics](#)
- [Vector Evaluation Test](#)

Mechanics

- [Force Concept Inventory](#)
- [Force-Motion Concept Evaluation](#)
- [Mechanics Baseline Test](#)
- [Energy Concepts Survey](#)

Heat, Temperature, and Thermodynamics

- [Heat and Temperature Concept Evaluation](#)

Waves

- [Wave Diagnostic Test](#)

E&M

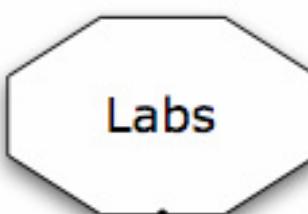
- [Conceptual Survey of Electricity and Magnetism](#)
- [Determining and Interpreting Resistive Electric Circuits Concept Test](#)
- [Electric Circuits Concept Evaluation](#)

Laboratory Concepts

- [Physics Measurement Questionnaire](#)
- [Measurement Uncertainty Quiz](#)

Curricular options: What's available?

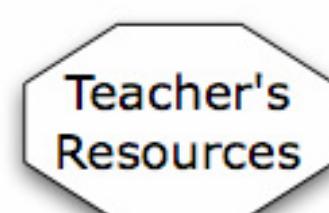
- A wide variety of research-based reform materials became available in the '90s.
 - Research is helping us understand what students need to do to learn physics more effectively.
 - Reform materials focus on creating environments in which students will learn more effectively.
 - Reform materials take into account common confusions and difficulties students have with the subject.



Interactive Lecture Demos
Peer Instruction
JiTT

RealTime Physics
Scientific Community Labs

Understanding Physics
Phys. for Sci. & Eng. (Knight)



Tutorials in Intro. Phys.
ABP Tutorials
Epistemological Tutorials.
Cooperative Problem Solving

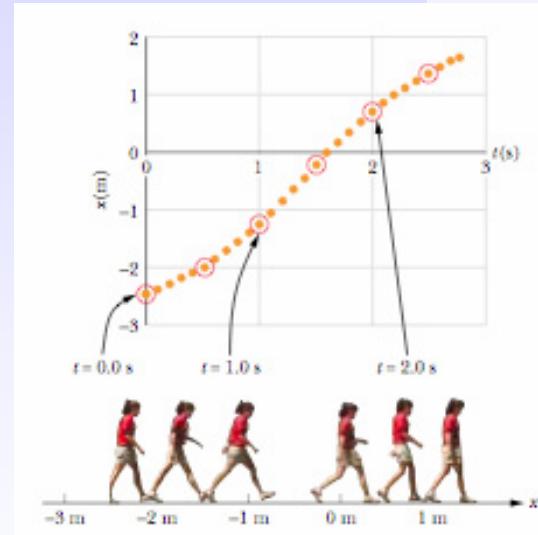
Workshop Physics
Explorations in Physics

Teaching Physics (Redish)
Action Research Kit (Surveys)
Five Easy Lessons (Knight)
Guide to Intro Phys (Arons)

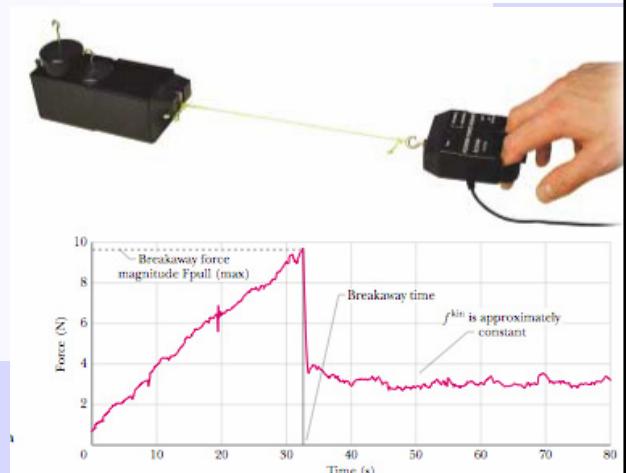
Workshop Physics* (N = 20 - 30)

In a WP room

- students use computer tools for observation and modeling
- guided inquiry model
- instructor in the room's center can see all computer screens at once.
- class can easily switch from small to large group discussion.



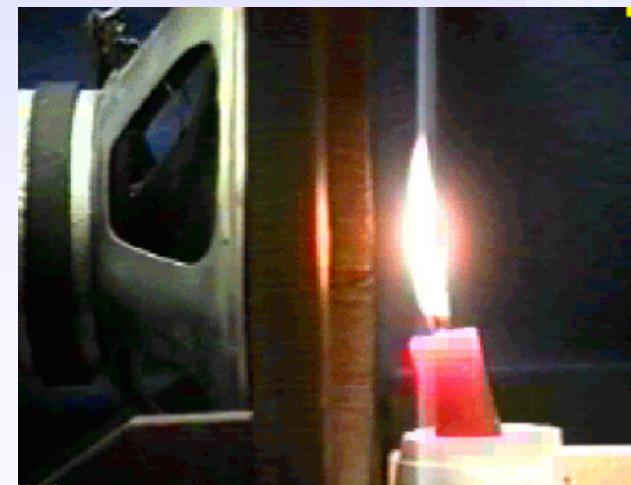
* Priscilla Laws, Workshop Physics Activity Guide
(John Wiley & Sons, 1997)



Tutorials (N=20-30 subsets)

- Tutorials are research-based worksheets and facilitators done in small groups (3-4).
- Elements contain
 - pretest
 - research-based worksheet
 - training session for TAs
 - tutorial homework
 - exams have a tutorial question

* L. C. McDermott, et al., *Tutorials In Introductory Physics*
(Prentice Hall, NY, 1998)



Different instructional models produce better conceptual gains

- We gave the FCI before and after instruction in 1st semester university physics in 15 universities who used 4 instructional models:
 - traditional (lecture) + recitation
 - traditional (lecture) + tutorial (RB)
 - traditional (lecture) + group problem solving (RB)
 - workshop physics. (RB)
- We observed both primary and secondary implementations of the research-based curricula.

*J. M. Saul and E. F. Redish, "Evaluation of the Workshop Physics Dissemination Project", U. of Maryland preprint, April 1998

**With modified
instruction
(N=280)**

- Imagine a head-on collision between a large truck and a small compact car. During the collision:

- (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
- (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
- (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
- (D) the truck exerts a force on the car but the car does not exert a force on the truck.
- (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

Pre Post

62% **16%**

2% **1%**

1% **0%**

0% **0%**

35% **83%**



Results

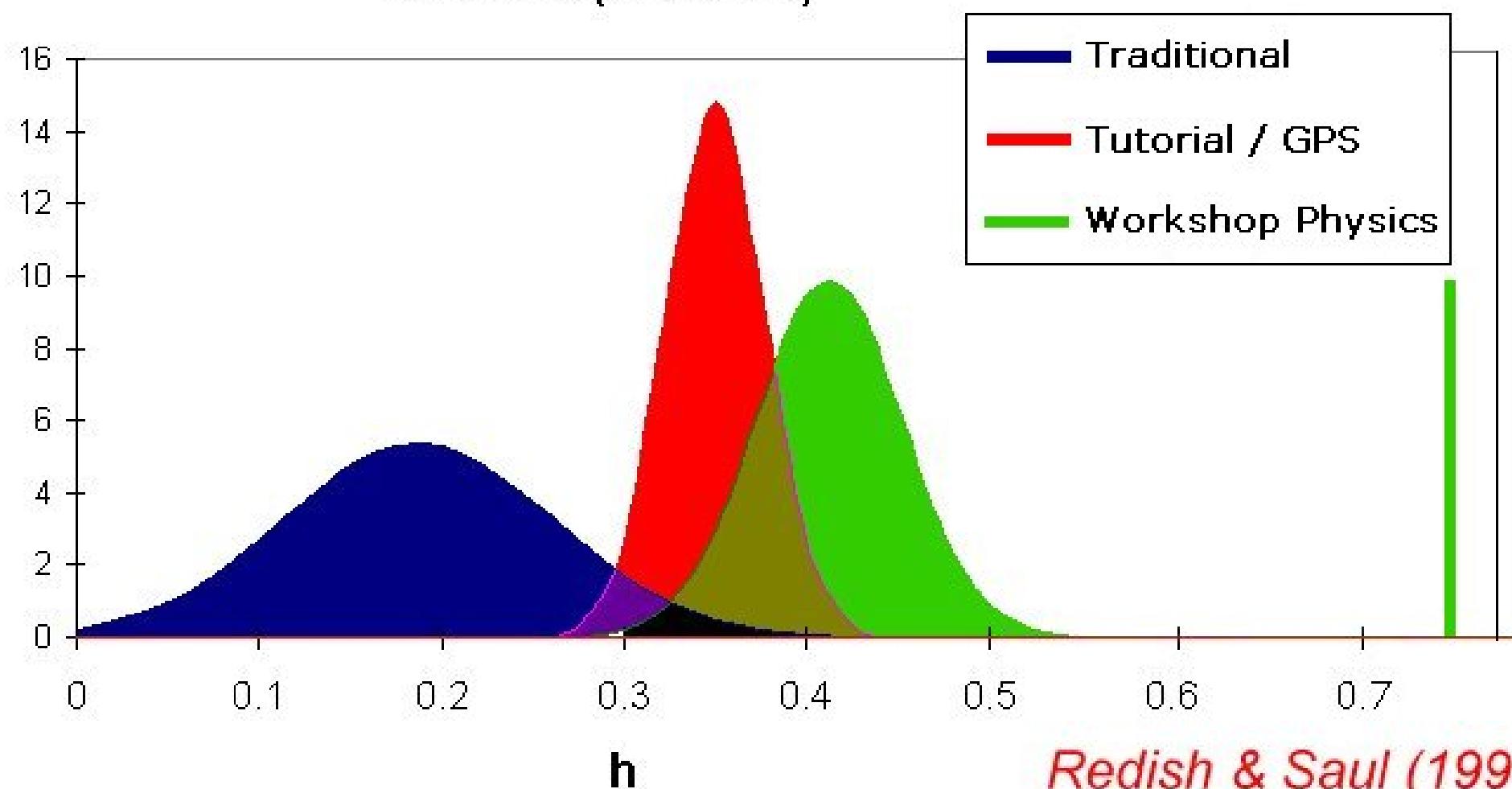
- The research-based curricula showed improvement in the fraction of the possible gain in concept learning as measured by the FCI:

$$h = \frac{(posttest\ average - pretest\ average)}{(100 - pretest\ average)}$$

$h = 0.20 \pm 0.03$	traditional
$h = 0.34 \pm 0.01$	recitation modifications
$h = 0.41 \pm 0.02$	Workshop Physics (early secondary implementations)
$h = 0.73$	(Dickinson College)

FCI Conceptual Learning Efficiencies

Distribution of h for various instructional methods (idealized)

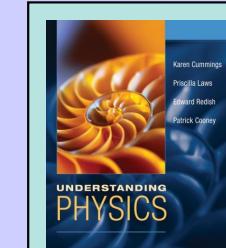


Redish & Saul (1998)

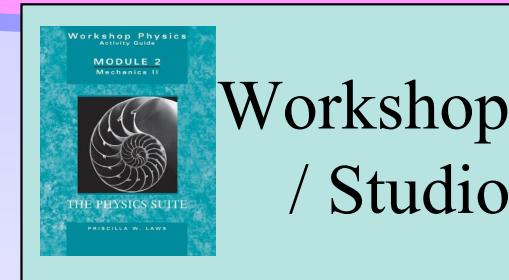
The 2000's

- Synthesized environments
 - SCALE-UP
 - Studio Physics
 - Illinois
- Environments that go beyond concept learning
- Textbooks beginning to be affected by PER
- The Physics Suite
- Theory development?

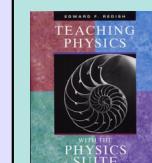
Elements of The Physics Suite



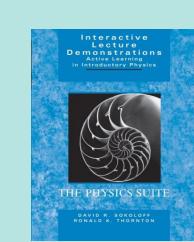
Narrative



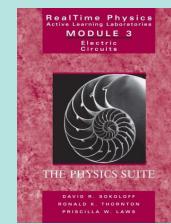
Workshop / Studio



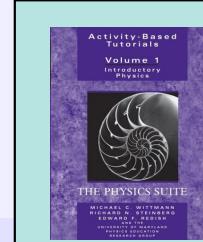
Guide to philosophy of the Suite



Lecture tools



Lab



Tutorials

Current State of PER

- 30+ PhD granting physics departments with education research programs
- 49 tenure line junior faculty on “young per” mailing list (acc. to M. Wittmann)
- Annual 1.5-day PER Conference appended to AAPT national meeting (since 1997)
 - Attendance ~200
 - Published proceedings since 2002
 - Next year to be published by AIP
- Gordon conference series (2000, 2002...)

Journals

- Science Education (1916/1961)
- Journal of Research in Science Teaching (1962)
- American Journal of Physics (as of 1972)
- Cognitive Science (1976)
- Cognition and Instruction (1982)
- Journal of the Learning Sciences (1991)
- American Journal of Physics: PER Supplement (1999)
- Physical Review: Physics Education (2005)

**The Enrico Fermi Summer School:
Course CLVI, Physics Education Research
Varenna, Lake Como, Italy
July 2003**



Methods

- Large N (standardized tests and surveys)
 - Pre/post assessments of progress understanding, attitudes, epistemologies
 - Some predictive testing of models
- Small N (interviews and in situ observations)
 - New: authentic data via videotape
 - Discovery and documentation of phenomena
 - Detailed analysis of dynamics

Current areas of research

- Phenomenology
 - Misconceptions
 - Epistemologies
 - Variability
- Theories of cognitive structure and mechanism

Sociology / Acceptance?

- Tools
 - Book (Arons '90)
 - Conferences (Raleigh '88, College Park '96)
 - Easily deliverable surveys (FCI, FMCE, MPEX)
 - Lectures and Colloquia
(McDermott, Hestenes, Mazur, Redish)
 - Materials that work
 - APS support statement ('99)
 - On-line review journal ('05)
- Some successes
 - Kansas State, Maine, Maryland, NCState, Washington

The UMd PERG (2004):

- Faculty
 - Joe Redish* (Ph)
 - David Hammer* (Ph / C&I)
 - Emily van Zee (C&I)
- Research Faculty
 - Rachel Scherr* (Ph)
 - Andy Elby* (Ph)
- Grad Students
 - Leslie Atkins (Ph)
 - Paul Hutchinson* (C&I)
 - Tim McCaskey* (Ph)
 - Paul Gresser* (Ph)
 - Ray Hodges* (Ph)
 - Rosemary Russ (Ph)
 - Mattie Lau (C&I)
 - Renee-Michelle Goertzen (Ph)
 - Tom Bing (Ph)

Physics
Curriculum & Instruction
Both

* Participants in LtLS
[...] = LtLS alumni