Physics Education Research and Research-Based Instructional Strategies

Action research and professional development in math, science and technology education

April 2, 2008

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Overview

- Part 1: Introduction to Physics Education Research
- Part 2: Putting Physics Education Research into Practice: An Example of Instructional Reforms at Western Michigan University

What is Physics Education Research (PER)?

A field dedicated to increasing our fundamental knowledge about the teaching and learning of physics.

Within the past 25 years, university-based physicists have begun to treat the teaching and learning of physics as a research problem

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

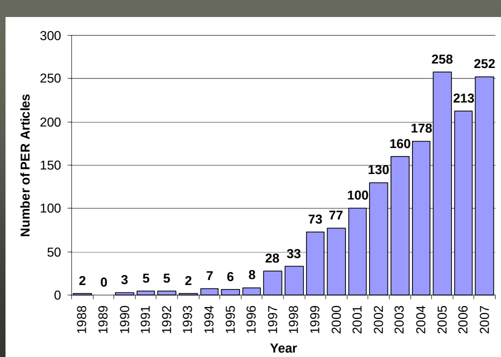
PER is an Exploding Field

PER PhD's in US*	
Through 1987	~6
1988-1997	~19
1998-2007	~70

- First annual PER conference was held in 1997 with about 50 attendees. Recent years have had ~250 attendees.
- Number of faculty and post-doc positions has outnumbered PER's on job market in recent years.
- New Journals:
  - Physics Education Section of American Journal of Physics – started in 1999
  - Proceedings (Peer Reviewed) of PER Conference – started in 2001
  - Physical Review Special Topics: Physics Education Research – started in 2005

*PER PhD Data from David Meltzer, Feb 2008.

Number of PER Publications is Increasing*



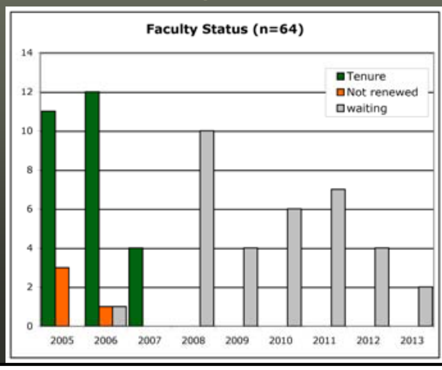
*Based on Google Scholar search on keyword "Physics Education Research" conducted March 2008

PER is Gaining Recognition from Traditional Physicists

from American Physical Society (APS) Statement on Research in Physics Education (1999)

"…The APS applauds and supports the acceptance in physics departments of research in physics education… PER can and should be subject to the same criteria for evaluation as research in other fields of physics. The outcome of this research will improve the methodology of teaching and teaching evaluation."

PER PhDs are Getting Hired and Getting Tenure*



*from Michael Wittmann, Feb 2008

Why Now?

The Force Concept Inventory: A 30 question multiple-choice test commonly used to assess student understanding of Newton's Laws.

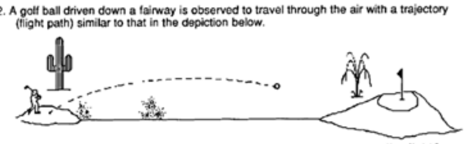
2. Imagine a head-on collision between a large truck and a small compact car. During the collision,

(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 doesn't 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.

Answer choice	Traditional Instruction	PER Instruction*
E-correct	22% ⇨ 37%	14% ⇨ 94%
A	72% ⇨ 60%	84% ⇨ 6%

*Swackhamer course, all data from Hestenes et. al., Force Concept Inventory (1992)

22. A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below.



Which following force(s) is(are) acting on the golf ball during its entire flight?

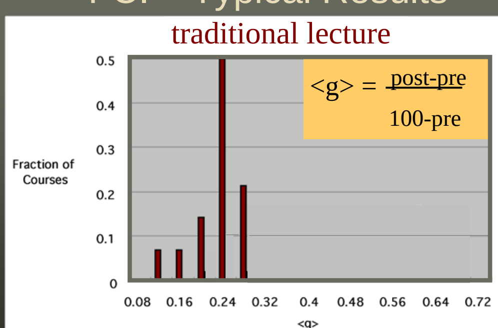
1. the force of gravity
2. the force of the "hit"
3. the force of air resistance

(A) 1 only
(B) 1 and 2
(C) 1, 2, and 3
(D) 1 and 3
(E) 2 and 3

Answer choice	Traditional Instruction	PER Instruction*
D-correct	10% ⇨ 29%	5% ⇨ 46%
C	79% ⇨ 62%	88% ⇨ 25%

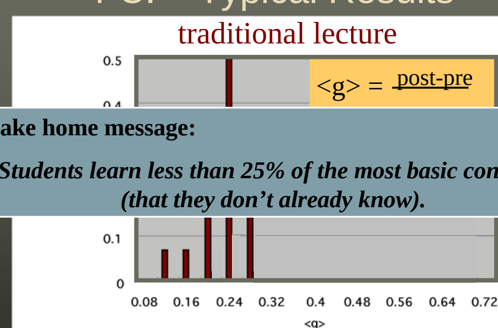
*Swackhamer course, all data from Hestenes et. al., Force Concept Inventory (1992)

FCI – Typical Results



R. Hake, "…A six-thousand-student survey…" AJP **66**, 64-74 ('98).

FCI – Typical Results



Take home message:

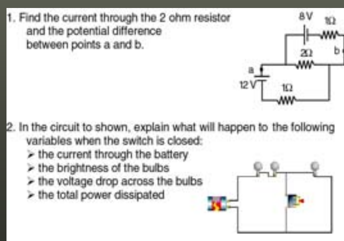
Students learn less than 25% of the most basic concepts (that they don't already know).

R. Hake, "…A six-thousand-student survey…" AJP **66**, 64-74 ('98).

Problems at Harvard (and elsewhere)
Rote Problem Solving

- (University) Students fail to learn basic concepts in (introductory physics) classes.

E.g.



~75%

~40%

From: Mazur (1997)

Problems at Harvard (and elsewhere)
Rote Problem Solving

- (University) Students fail to learn basic concepts in (introductory physics) classes.

Take home message:

Many students (even at Harvard) solve problems by rote without understanding the underlying physics concepts.

Corollary:

Traditional problem solving is a poor measure of student understanding.

From: Mazur (1997)

Generalizations from empirical research in traditionally taught physics courses*

Research has shown that student performance on certain basic, qualitative questions is essentially the same:

- before and after traditional (lecture) instruction
- in courses with and without calculus
- in courses with and without a standard lab
- in courses with and without demonstrations
- in large and small classes
- regardless of proficiency of the lecturer

* L.C. McDermott, AIP Conf. Proc. **399**, 139 – 165 (1997).

Critical limitations of traditional instruction*

- Teaching by telling is an ineffective mode of instruction for most students.

  Students must be intellectually active to develop a *functional understanding* of the content (*i.e.*, the ability to do the reasoning needed to apply concepts and principles in situations not previously memorized).

*L.C. McDermott, Am. J. Phys. **61**, 295 – 298 (1993).

The Monotillation of Traxoline*

It is very important that you learn about traxoline. Traxoline is a new form of zionter. It is montilled in Ceristanna. The Ceristannians gristerlate large amounts of fevon and then brachter it to quasel traxoline. Traxoline may well be one of our most lukized snezlaus in the future because of our zionter lescelidge.

Directions: Answer the following questions.

1. What is traxoline?
2. Where is traxoline montilled?
3. How is traxoline quasselled?
4. Why is it important to know about traxoline?

* attributed to Judy Lanier

Some principles and strategies for effective instruction in physics*

- Concepts, reasoning ability, and representational skills should be developed together in a coherent body of subject matter.
- The ability to make connections between the formalism of physics and real-world phenomena must be expressly developed.
- Common conceptual and reasoning difficulties that students encounter must be explicitly addressed.
  - Questions that require explanations of reasoning are essential for probing student thinking and assessing student progress.

*L.C. McDermott, Am. J. Phys. **59**, 301 – 315 (1991).

Some Examples of PER Solutions

- Replace lecture with hands-on, inquiry based activities.
- Encourage and support cooperative learning.
- Explicitly teach problem solving.

Traditional Physics class at University of Rochester

SCALE-UP Physics class at Clemson University

NC State Studio Classroom

MIT Studio Physics

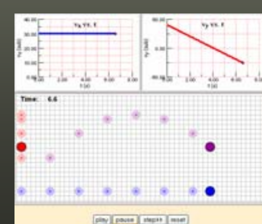
Active classes make active students (on task)

*Belcher, http://www-caes.mit.edu/research/teal/index.html

Technology

Classroom Response Systems

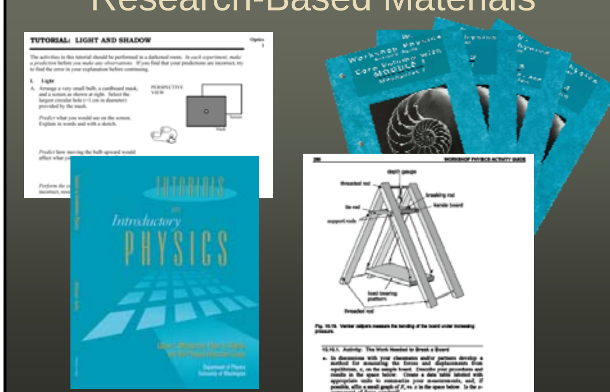
Java Applets



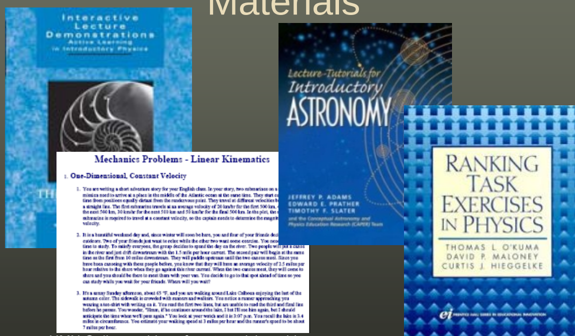
Research-Based Nationally-Normed Assessments

From: http://www.ncsu.edu/per/TestInfo.html

Research-Based Materials



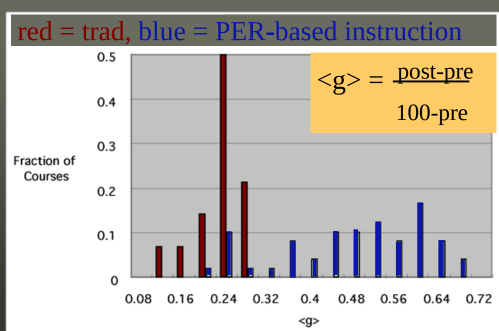
More Research-Based Materials



UMN Online archive of context-rich problems:
http://groups.physics.umn.edu/physed

Books that summarize it all!

Back to the FCI



R. Hake, "…A six-thousand-student survey…" AJP **66**, 64-74 ('98).

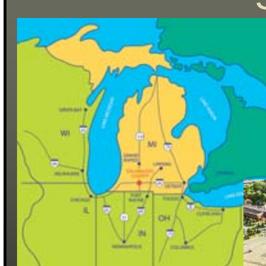
Challenges Ahead

- PER-based materials and strategies are not used as frequently as they could be.
- More on this tomorrow….

PER-Based Reforms at Western Michigan University

Examples of research-based reforms to the introductory calculus-based physics sequence.

Setting



~25,000 Students

18 physics faculty

Physics B.S., M.S., Ph.D.

WMU is one of 6 Original Physics Teacher Education Coalition (PhysTEC) Institutions

PhysTEC Mission: To improve and promote the education of future physics and physical science teachers.

Main Project Goal: Produce more better-prepared elementary, middle, and high school teachers, committed to interactive, inquiry-based approaches to teaching

- **Ball State University**
- **Oregon State University**
- **University of Arkansas**
- **University of Arizona**
- **Xavier University of Louisiana**
- **Western Michigan University**

WMU Intro Calculus-Based Physics

Physics 2050: Mechanics (Berrah, Famiano, Henderson, Paulius)

Physics 2070: Electricity and Magnetism (Rosenthal, Henderson)

- Lecture
- Large Class (~70 students)
- Every day, 1 hour
- Implementation of interactive engagement approaches

- Laboratory
- Small Class (~20 students)
- 1 day/week, 2 hours
- New labs based on an elicit-confront-resolve instructional framework

Design Principles of WMU PhysTEC "Lectures"

(Departures from traditional instruction)

1. **Students should be actively engaged with the material during class time. This is best accomplished via student-student interaction.**
2. **Students should read the text before coming to class and most will not do this unless there is some sort of enforcement.**
3. **Class discussions and tests should place significant emphasis on conceptual issues and qualitative questions.**
4. **Class discussions and tests should place significant emphasis on the solving of multi-step problems (i.e., ones that cannot be solved by substituting numbers into a single equation).**
5. **Student problem solutions should start from basic principles and contain written explanation of reasoning.**
6. **Test questions should require students to engage in the desired thinking processes. This means that test questions should not be similar enough to questions students have previously seen that a rote strategy is fruitful.**
7. **Formative assessment, both informal and formal, should be used to determine students' current understanding for the purpose of designing appropriate subsequent instruction.**
8. **Depth of student understanding should be valued more than breadth of content covered during the course.**

Three Core Changes
to "lecture" Course

- Interactive class sessions
- Use of non-traditional problems
- Focus course on small number of main ideas

Change 1:Interactive Class Sessions

White Boards and Group Work

Interactive Lectures

Reading Questions

(Encourage students to read the text and provides instructor with insight into student thinking)

Students are required to submit one or more questions about each reading assignment.

Example Submissions:

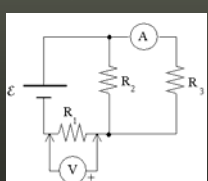
- Are electrical field lines made by two charges instantaneous? If two charges are next to each other wouldn't they move closer or further away, depending on charge, therefore constantly changing the field lines?
- A charge creates a electrical field. If the charge is positive then the particle attracts negative charges. Is there a point at which a single charge, for example a proton, cannot attract anymore negative particles?

C. Henderson and A. Rosenthal, "Reading questions: Encouraging students to read the text before coming to class," Journal of College Science Teaching. **35** (7), 46-50 (2006).

Change 2: Non-Traditional Problems

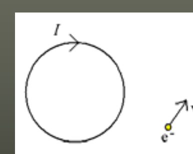
In circuit #1, all resistors have equal resistance and look like the resistor labeled A. The readings of voltmeter and ammeter are specified.

In circuit #2, R_3 is replaced by B, with same length and material composition as A but twice the diameter. Find new meter readings.



Conceptual Questions

An electron is moving as shown in the region near a circular current-carrying loop of wire. Is there a force on the electron? If yes, find the direction of this force. If no, explain why not.

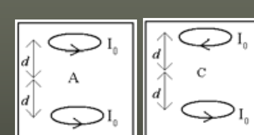


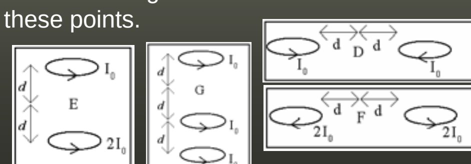
Multi-Step Problems

Your are working as a roadie for the circus. In one act, Marcello (mass 70 kg) is shot from a cannon with a muzzle velocity of 24 m/s at an angle of 30o above the horizontal. His partner Tina (mass 50 kg) stands on an elevated platform located at the top of the trajectory. He grabs her as he flies by and the two fly off together and land in a net at the same elevation as the cannon. Because of your physics knowledge you are asked to determine how far away from the cannon to place the net.

Ranking Tasks

Six points, A – G are located as shown near current carrying coils (of identical radii). Rank, from greatest to least, the magnitude of the magnetic field at these points.





O'Kuma, T., Maloney, D. P., & Hieggelke, C. J. (1999). *Ranking Task Exercises in Physics: A User's Manual*. Upper Saddle River, NJ: Prentice Hall.

Problem Solution Requirements

<u>General Approach</u> Identify what type of problem this is and (in a sentence or two) your basic approach to solving it.

What should be included:
- **Classification of problem**
- **Overview of your approach to the problem**

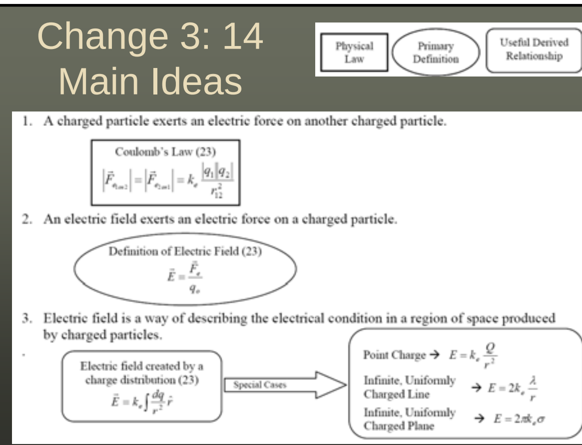
<u>Procedure</u> Explain how you will use the course main ideas to follow the general approach and why you will use them that way.

What should be included:
- **Diagram**
- **Explanation of reasoning and assumptions**
- **Must start from one of the main ideas (and not from a derived equation from text)**

<u>Implementation</u> Show how following the procedure leads to a plausible result.

What should be included
- **Mathematical operations**
- **Evaluation of final result**

Change 3: 14 Main Ideas



Success of Innovations
Conceptual Exam Scores

Semester	FCI normalized gain
F'02	0.33
S'03	0.50
F'03	0.51
F'04	0.51
S'05	0.53

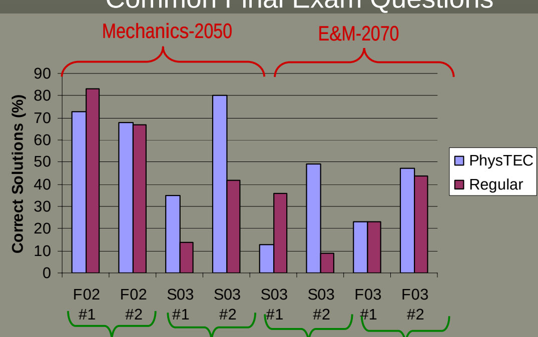
Comparison:
Natl. average traditional course is 0.23
Natl. average interactive course is 0.48

Success of Innovations
Conceptual Exam Scores

semester	CSEM normalized gain
S'03	0.40
F'03	0.30
S'04	0.34
F'04	0.48
S'05	0.35
F'06	0.47

Comparison:
Natl. average traditional course is 0.14
Natl. average interactive course is 0.28

Success of Innovations
Solving Standard Problems: Common Final Exam Questions



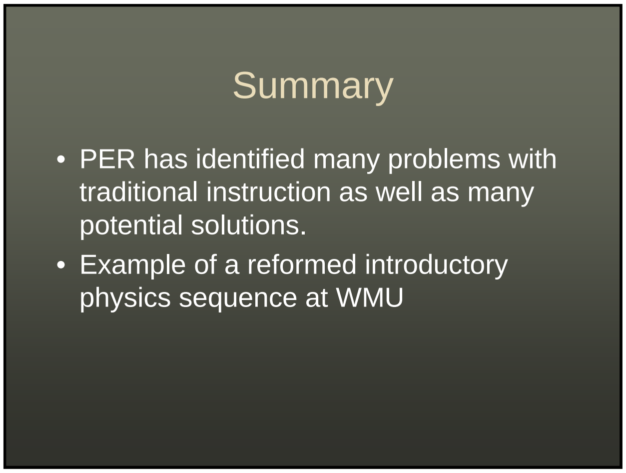
Success of Innovations
Solving Standard Problems: Common Final Exam Questions

Take home message:

The PhysTEC innovations have significantly improved student conceptual understanding and have not significantly changed their success at solving standard physics problems.

Corollary:

Of course, we'd like to also improve their ability to solve standard problems


Summary
• PER has identified many problems with traditional instruction as well as many potential solutions.
• Example of a reformed introductory physics sequence at WMU