

Physics Education Research and Research-Based Instructional Strategies

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

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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

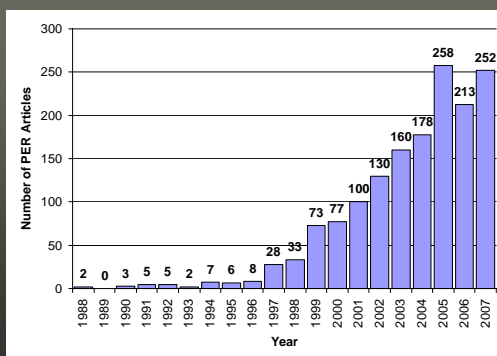
PER is an Exploding Field

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*



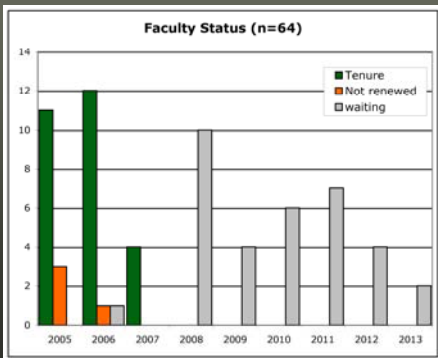
*Based on Google Scholar search on keyword "Physics Education Research" conducted March 2008

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

Force Concept Inventory

Why Now?

By David Hestenes, Malcolm Wells, and Gregg Swackhamer

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

Force Concept Inventory

David Hestenes is a professor of theoretical physics at Arizona State University. He has been active in physics education research for more than 30 years. He has received several awards for his research in science education theory and research, including the 2007 American Physical Society Award for Distinguished Contributions to Physics Education.

Malcolm Wells has been a high school physics teacher for 20 years. He has been active in physics education research for more than 10 years. He has received several awards for his research in science education theory and research, including the 2007 American Physical Society Award for Distinguished Contributions to Physics Education.

Gregg Swackhamer has taught high school physics for 12 years. He has been active in physics education research for more than 10 years. He has received several awards for his research in science education theory and research, including the 2007 American Physical Society Award for Distinguished Contributions to Physics Education.

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.

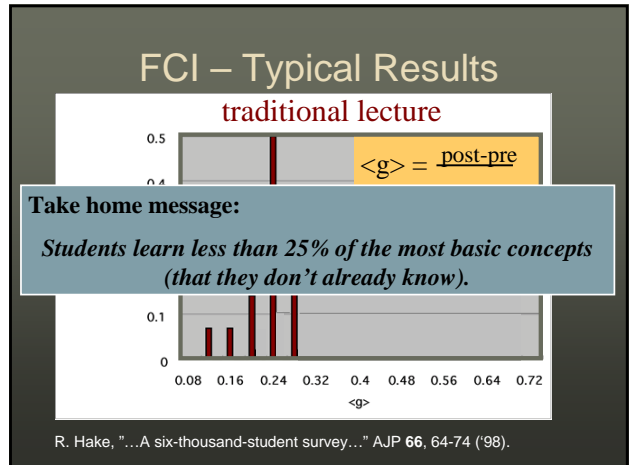
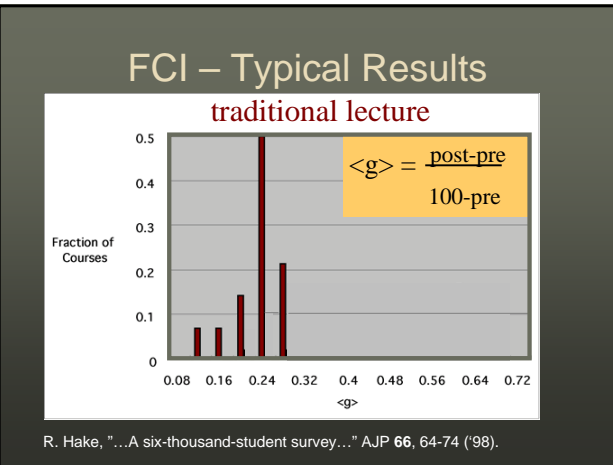
Which following force(s) is (are) acting on the golf ball during its entire flight?

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)

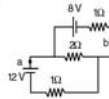


Problems at Harvard (and elsewhere) Rote Problem Solving

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

E.g.

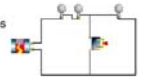
1. Find the current through the 2 ohm resistor and the potential difference between points a and b.



~75%

2. In the circuit to shown, explain what will happen to the following variables when the switch is closed:

- the current through the battery
- the brightness of the bulbs
- the voltage drop across the bulbs
- the total power dissipated



~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 lesceledge.

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)

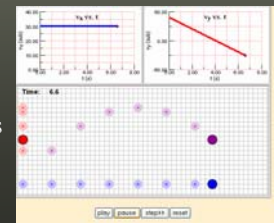
*Belcher, <http://www-caes.mit.edu/research/teal/index.html>

Technology



Classroom Response Systems

Java Applets



Research-Based Nationally-Normed Assessments

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

THE ASSESSMENT
Assessment Instrument Information Page
Version 2.0 (2004)

Below is a list of assessment instruments that are available for use in your course. Each instrument is described in terms of its purpose, format, and availability. For more information about any of these instruments, please contact the person listed in the "Contact" column. For a complete list of assessment instruments, please visit the www.ncsu.edu/per/assessments page.

Assessment Instrument	Description	Contact
1011 The National Survey of Student Engagement (NSSE)	A national survey of student engagement that measures student involvement in learning activities and institutional resources.	www.ncsu.edu/per/nsse
1012 The National Survey of Science and Technology Attitudes (NSSTA)	A national survey of science and technology attitudes that measures students' attitudes toward science and technology.	www.ncsu.edu/per/nssta
1013 The National Survey of Engineering Attitudes (NSEA)	A national survey of engineering attitudes that measures students' attitudes toward engineering.	www.ncsu.edu/per/nsea
1014 The National Survey of Physics Attitudes (NSPA)	A national survey of physics attitudes that measures students' attitudes toward physics.	www.ncsu.edu/per/nspa
1015 The National Survey of Chemistry Attitudes (NSCA)	A national survey of chemistry attitudes that measures students' attitudes toward chemistry.	www.ncsu.edu/per/nsca
1016 The National Survey of Biology Attitudes (NSBA)	A national survey of biology attitudes that measures students' attitudes toward biology.	www.ncsu.edu/per/nsba
1017 The National Survey of Environmental Science Attitudes (NSESA)	A national survey of environmental science attitudes that measures students' attitudes toward environmental science.	www.ncsu.edu/per/nsea
1018 The National Survey of Earth Science Attitudes (NSEA)	A national survey of earth science attitudes that measures students' attitudes toward earth science.	www.ncsu.edu/per/nsea
1019 The National Survey of Atmospheric Science Attitudes (NSASA)	A national survey of atmospheric science attitudes that measures students' attitudes toward atmospheric science.	www.ncsu.edu/per/nsasa
1020 The National Survey of Oceanography Attitudes (NSOA)	A national survey of oceanography attitudes that measures students' attitudes toward oceanography.	www.ncsu.edu/per/nsoa
1021 The National Survey of Planetary Science Attitudes (NSPSA)	A national survey of planetary science attitudes that measures students' attitudes toward planetary science.	www.ncsu.edu/per/nspsa
1022 The National Survey of Space Science Attitudes (NSSSA)	A national survey of space science attitudes that measures students' attitudes toward space science.	www.ncsu.edu/per/nsssa
1023 The National Survey of Astrophysics Attitudes (NSA)	A national survey of astrophysics attitudes that measures students' attitudes toward astrophysics.	www.ncsu.edu/per/nsa
1024 The National Survey of Cosmology Attitudes (NSCA)	A national survey of cosmology attitudes that measures students' attitudes toward cosmology.	www.ncsu.edu/per/nsca
1025 The National Survey of Particle Physics Attitudes (NSPPA)	A national survey of particle physics attitudes that measures students' attitudes toward particle physics.	www.ncsu.edu/per/nsppa
1026 The National Survey of Nuclear Physics Attitudes (NSNPA)	A national survey of nuclear physics attitudes that measures students' attitudes toward nuclear physics.	www.ncsu.edu/per/nsnpa
1027 The National Survey of Quantum Physics Attitudes (NSQPA)	A national survey of quantum physics attitudes that measures students' attitudes toward quantum physics.	www.ncsu.edu/per/nsqpa
1028 The National Survey of Relativity Attitudes (NSRA)	A national survey of relativity attitudes that measures students' attitudes toward relativity.	www.ncsu.edu/per/nsra
1029 The National Survey of String Theory Attitudes (NSTA)	A national survey of string theory attitudes that measures students' attitudes toward string theory.	www.ncsu.edu/per/nsta
1030 The National Survey of Superstring Theory Attitudes (NSSSTA)	A national survey of superstring theory attitudes that measures students' attitudes toward superstring theory.	www.ncsu.edu/per/nsssta

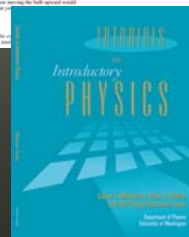
Research-Based Materials

TUTORIAL: LIGHT AND SHADOW

The activities in this tutorial should be performed in a laboratory setting. It is an experiment, and it will require you to make your own observations. It is not a lecture, and you are not expected to find the answer to your questions before continuing.

1. **OBJECTIVE**
 A. Arrange a very small hole, a cardboard mask, and a screen in a line. Measure the distance between the hole and the screen. Predict what you would see on the screen. Explain to yourself what you see.

Provide your own explanation for what you see.



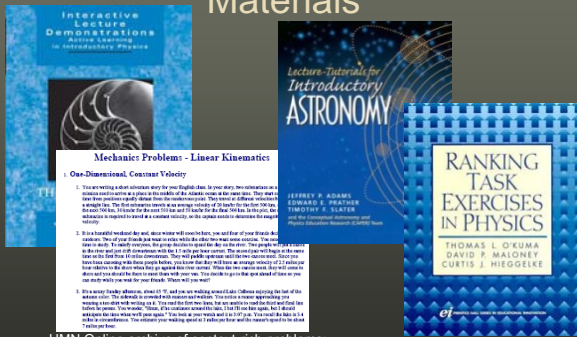
WORKBOOK: LIGHT AND SHADOW

FIGURE 1.10 Young's double-slit experiment illustrates the wave nature of light. The light from the two slits interferes constructively and destructively, creating a pattern of light and dark fringes on the screen.

1.10.1 Activity: The Wave Nature of Light's Source

In this activity, you will investigate the wave nature of light by observing the interference pattern of light from two slits. You will use a laser, a double-slit mask, and a screen. You will measure the distance between the slits and the distance to the screen. You will also measure the distance between the central maximum and the first minimum. You will then use these measurements to calculate the wavelength of the light. This activity is designed to help you understand the wave nature of light and the interference of light.

More Research-Based Materials



Mechanics Problem - Linear Kinematics
One-Dimensional Constant Velocity

1. The following is an abstract from the new English-11a. In your own two sentences or more, explain to a friend what the abstract is about. Be sure to include the key words. You must use the words *velocity* and *distance* in your explanation. The abstract is as follows: "The abstract is about a car moving at a constant velocity. It is a simple problem that requires the student to use the definition of velocity." (The abstract is a simple problem that requires the student to use the definition of velocity.)

2. In a hand-drawn diagram, show what will occur when you add force to your brick. Explain in words. Be sure to include the key words. The abstract is as follows: "The abstract is about a brick being pushed. It is a simple problem that requires the student to use the definition of force." (The abstract is a simple problem that requires the student to use the definition of force.)

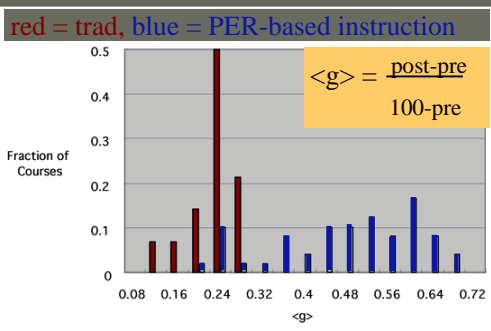
3. In a hand-drawn diagram, show what will occur when you add force to your brick. Explain in words. Be sure to include the key words. The abstract is as follows: "The abstract is about a brick being pushed. It is a simple problem that requires the student to use the definition of force." (The abstract is a simple problem that requires the student to use the definition of force.)

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:

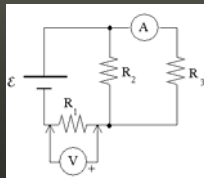
- Are electrical field lines made by two charges instantaneous? If two charges are next to each other wouldn't they move closer or further away, depending on charge, therefore constantly changing the field lines?
- A charge creates an electrical field. If the charge is positive then the particle attracts 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

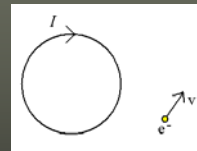
In circuit #1, all resistors have equal resistance and look like the resistor labeled A. The readings of voltmeter and ammeter are specified.

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.

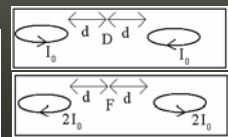
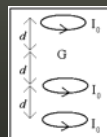
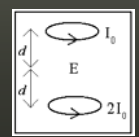
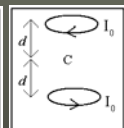
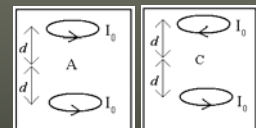


Multi-Step Problems

You 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 30° 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

General Approach 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

Procedure

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)

Implementation

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

Physical Law

Primary Definition

Useful Derived Relationship

1. A charged particle exerts an electric force on another charged particle.

$$\text{Coulomb's Law (23)} \\ |\vec{F}_{n,m}| = |\vec{F}_{m,n}| = k_e \frac{|q_n||q_m|}{r_{nm}^2}$$

2. An electric field exerts an electric force on a charged particle.

$$\text{Definition of Electric Field (23)} \\ \vec{E} = \frac{\vec{F}_e}{q_e}$$

3. Electric field is a way of describing the electrical condition in a region of space produced by charged particles.

$$\text{Electric field created by a charge distribution (23)} \\ \vec{E} = k_e \int \frac{dq}{r^2} \hat{r}$$

Special Cases

$$\begin{aligned} \text{Point Charge} &\rightarrow E = k_e \frac{Q}{r^2} \\ \text{Infinite, Uniformly Charged Line} &\rightarrow E = 2k_e \frac{\lambda}{r} \\ \text{Infinite, Uniformly Charged Plane} &\rightarrow E = 2\pi k_e \sigma \end{aligned}$$

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

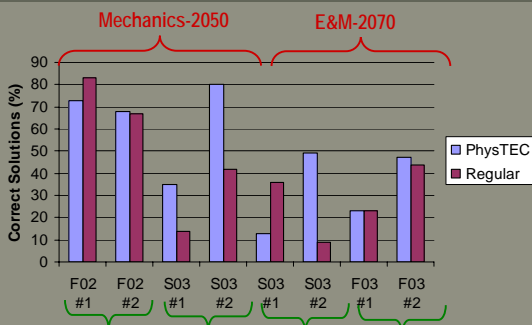
Comparison:
Natl. average traditional course is 0.23
Natl. average interactive course is 0.48

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