Top 10 Results of Physics Education Research that every physics instructor should know

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Outline

- Overview of Physics Education Research
- Top 10 Results of PER
  - Results
  - Caveats
  - Implications for Instruction

Physics Education Research (PER)

- Research on how students think about physics and how to teach physics more effectively
- Uses expertise in physics content
- Studies how students think about specific physics concepts
- Develops teaching methods that are demonstrated to teach physics more effectively
- Leads discipline-based research in other sciences by several decades

Top 10 Results of PER

1. Implementing PER improves learning.*
    a...for all students.
    b...and they retain it.
2. Everyday ideas matter.
3. Knowledge structure matters.*
4. Lectures rarely work.*
5. Demos rarely work.*
6. Problem-solving ↛ understanding.
7. Understanding → problem-solving.
8. Most physics classes harm students' beliefs.
    a...but not all of them do.
9. Beliefs affect learning.
10. Implementing PER requires understanding.

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1. **Implementing PER** improves learning.

Result: PER-based teaching methods improve student learning of physics.

1. **Implementing PER** improves learning.

Examples of PER-based teaching methods*

- Peer Instruction
- Tutorials in Introductory Physics
- Interactive Lecture Demonstrations
- Studio Physics
- SCALE-UP
- Workshop Physics
- ISLE
- Physics by Inquiry (PBI)
- Physics in Everyday Thinking (PET)
- Open Source Tutorials
- Cooperative Group Problem-Solving
- Learning Assistants Program
- PhET Interactive Simulations
- 50+ on PhysPort

*AKA interactive engagement methods, active learning methods

1. **Implementing PER** improves learning.

Qualities of PER-based teaching methods
(Meltzer and Thornton 2012)

1. Explicitly based on research
2. Interactive engagement
3. Evidence of effectiveness in classrooms

1. **Implementing PER** improves learning.

Qualities of PER-based teaching methods

(See What makes them work on PhysPort)

- Development through research
- Constructing understanding
- Active Engagement
- Conceptual focus
- Verbalizing thinking
- Peer discussion
- Group work
- Model-building
- Explicitly taking students' prior thinking into account
- Confronting student difficulties
- Building on students' productive resources
- Socratic dialog
- Commitment to an answer
- Formative assessment
- Rapid feedback
- Multiple representations
- Organizing knowledge
- Metacognition
- Explicitly addressing epistemology

1. Implementing PER **improves learning**.

Result: PER-based teaching methods **improve student of physics**.

Many studies showing improvements in:

- Conceptual understanding
- Problem-solving abilities:
  - Traditional textbook problems
  - Complex ill-formed problems
- Scientific reasoning abilities
- And more …

1. Implementing PER **improves learning**

Example: Measuring conceptual understanding:

Force Concept Inventory (FCI) (Hestenes 1992)

- Multiple choice survey
- Tests conceptual understanding of forces.
- Based on research on student thinking.
- Necessary (not sufficient) indicator of conceptual understanding.

1. Implementing PER **improves learning**

Sample FCI question

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. $F_{\text{T on C}} > F_{\text{C on T}}$

B. The car exerts a greater amount of force on the truck than the truck exerts on the car. $F_{\text{C on T}} > F_{\text{T on C}}$

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. $F_{\text{C on T}} = 0$

E. The truck exerts the same amount of force on the car as the car exerts on the truck. $F_{\text{T on C}} = F_{\text{C on T}}$

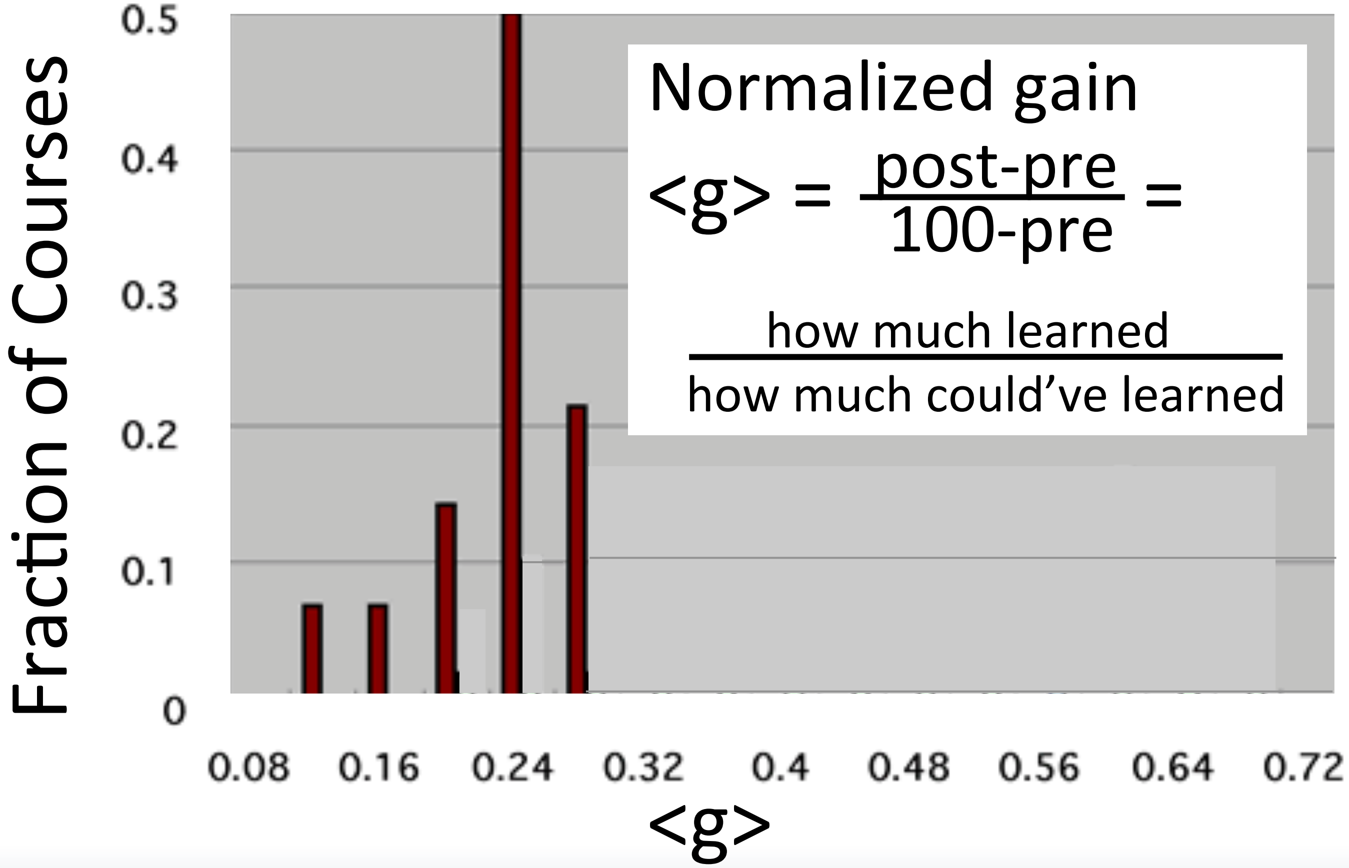
Newton's Third Law: For every action there is an equal and opposite reaction.

1. Implementing PER **improves learning**

Example: Measuring conceptual understanding:

A 6000-student survey of PER-based vs. lecture-based teaching methods

(Hake 1998)



Normalized gain

$$\langle g\rangle = \frac{\text{post-pre}}{\text{100-pre}} = \frac{\text{how much learned}}{\text{how much could've learned}}$$

🟥 Traditional lecture methods

🟦 PER-based teaching methods

1. Implementing PER improves learning.

Result: PER-based teaching methods improve student learning of physics.

Implication: Use PER-based teaching methods.

1. Implementing PER improves learning.

Caveat: What we **don't** know…

Which of the ~20 qualities of PER-based methods are most important and in which proportion?

Preliminary studies suggest:

- Studio physics may not work without research-based materials. (Cummings 1999)
- Tutorials may not work without Socratic dialog. (Koenig 2007)

1. Implementing PER improves learning.

Caveat: What we **don't** know…

Which of the ~20 qualities of PER-based methods are most important and in which proportion?

Future research needed:

- **Quantitative** analysis – Which factors are correlated with learning gains?
  (McKagan & Sayre, NSF WIDER grant 2012-14)
- **Qualitative** analysis – What actually happens in successful classrooms?

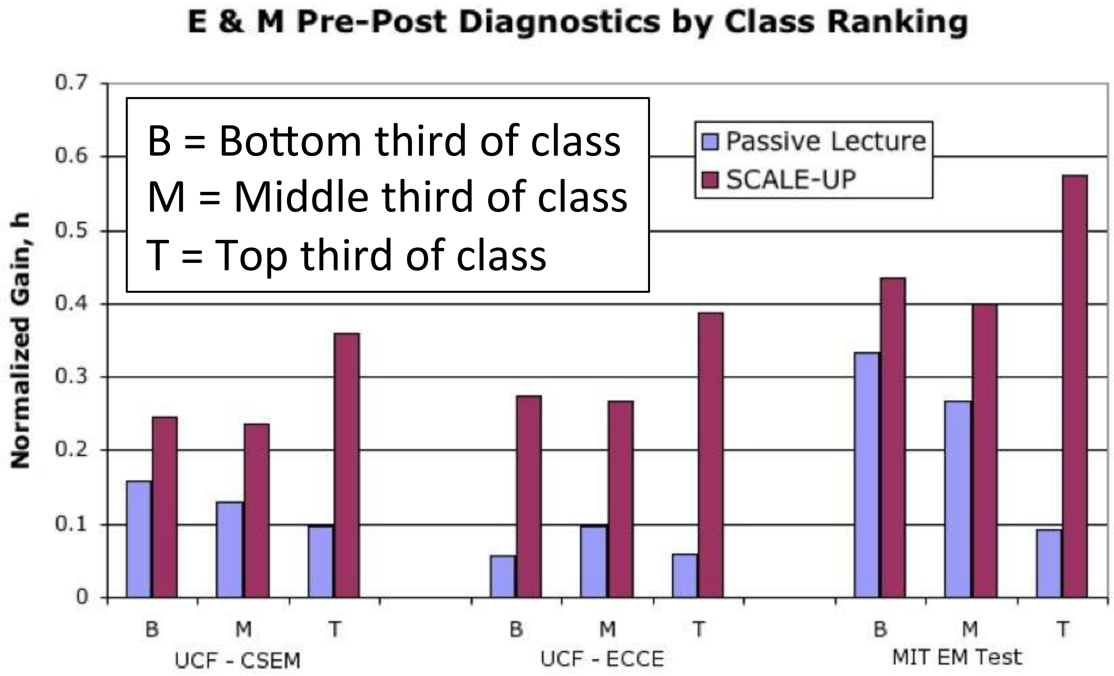
1a. …for all students.

Result: PER-based teaching methods improve student learning of physics *for students at all ability levels*.

1a. …for all students.

Examples:

- **SCALE-UP:**



(Beichner 2007)

- **Cooperative Group Problem Solving**: solutions of group better than those of strongest student in group (Heller 1992)
- **Peer Instruction:** No student answers more than 80% of concept questions correctly. (Crouch 2001)

1b. …and they retain it.

Result: PER-based teaching methods improve student learning of physics and *the results last for multiple years*.

1b. …and they retain it.

Examples:

- Students using **Tutorials** have large learning gains on FCI, very little drop in scores after 1, 2, or 3 years. (Francis 1998)
- Students using **Physics by Inquiry** have much higher scores than others on two different tests, no change in scores after 1 year. (McDermott 2000)
- Physics majors who took intro E&M with **Tutorials** got better grades in Junior E&M. (Pollock 2009)

1. Implementing PER improves learning.

Results:

PER-based teaching methods improve student learning of physics

a. for students at all ability levels, and

b. the results last for multiple years.

Implications:

Use PER-based teaching methods.

a. Use them even for your best students.

b. They will provide more than a quick fix.

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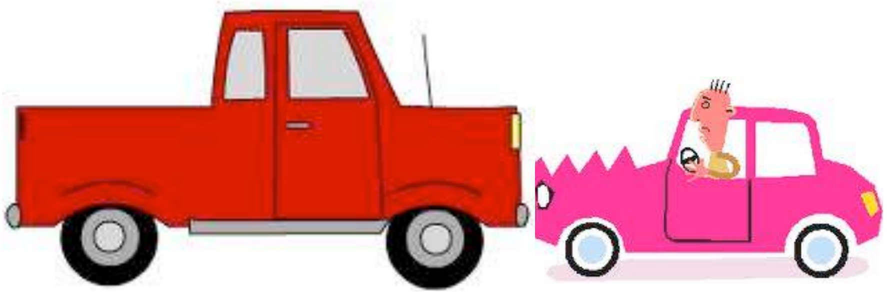
    a...but not all of them do.
9. Beliefs affect learning.
10. Implementing PER requires understanding.

2. Everyday ideas matter.

Result: Students' everyday ideas about the world affect their learning of physics.

2. Everyday ideas matter.

Examples: research identifying specific misconceptions, difficulties, and productive resources



Difficulty: Students think a truck exerts a larger force on a car than the car exerts on the truck.

Productive resource: Students understand that some aspect of impact of truck on car is bigger than impact of car on truck.

2. Everyday ideas matter.

Result: Students' everyday ideas about the world affect their learning of physics.

Curriculum based on students' ideas is more effective. (McDermott 1992-2013, Smith 2007)

Teachers who are aware of students' ideas are more effective. (Sadler 2013)

Implication: Seeing the world from your students' perspective will make you a more effective teacher.

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3. Knowledge structure matters.

Result: Learning physics requires not only acquiring knowledge, but developing a framework for organizing that knowledge.

Examples: research on experts and novices solving problems

Implication: Focus on ways to develop your students' framework for knowledge, not just to increase their content knowledge.

Caveat: We don't know exactly how to do this!

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4. Lectures rarely work.

Result: Traditional lectures rarely change students' everyday ideas or knowledge structure.

Students rarely learn much from them.

4. Lectures rarely work.

Examples:

- FCI studies:
  lecture vs. PER-based methods (Hake 1998)
- Laboratory experiments:
  students answer questions after watching award-winning lectures (Hrepic 2007)
  - Remember the opposite of what was said
  - Correctly remember what was said but misinterpret it
  - Retain original ideas without recognizing statements that contradict them

4. Lectures rarely work.

Caveat: It is possible for to learn from lecture ***if***:

- The lecture addresses questions the students are asking themselves,
- The students are actively working to make sense of what they are hearing, ***and***
- The students have a framework that the content of the lecture fits into.

(Schwartz 1998, 2011)

4. Lectures rarely work.

Result: Traditional lectures rarely change students' everyday ideas or knowledge structure.

Students rarely learn much from them.

Caveat: Unless they're primed to learn.

Implication: Intersperse lectures with activities that engage students and get them asking questions that the lectures will answer. Or change to whole format of your course.

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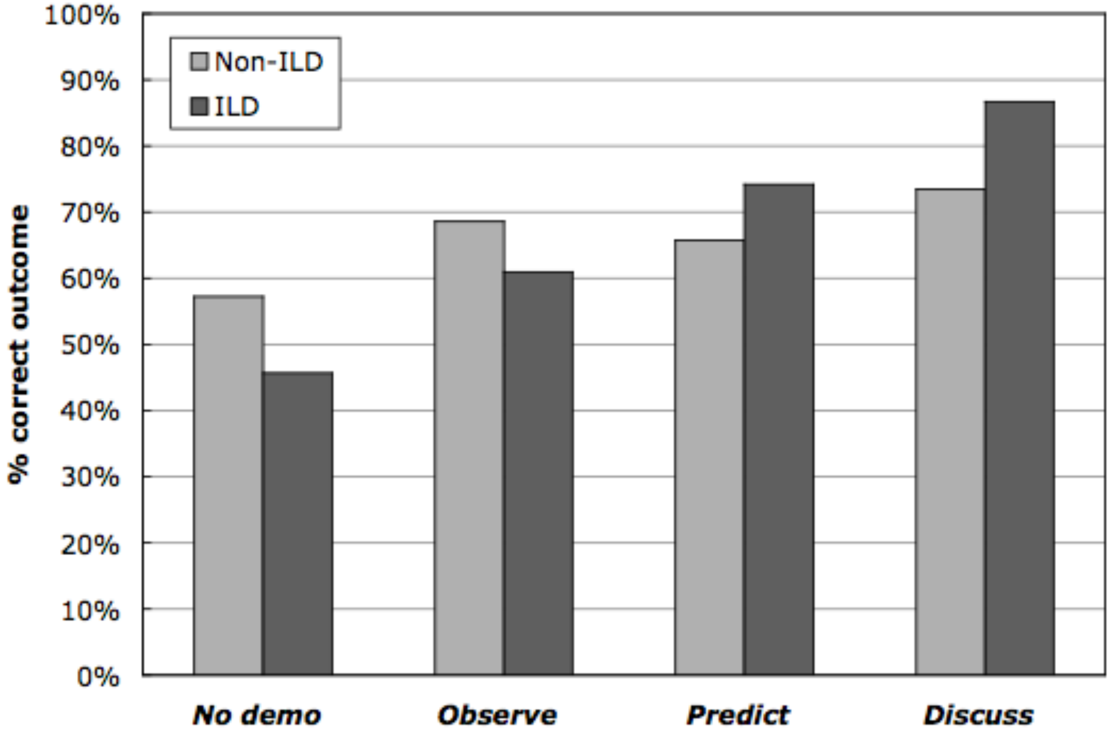
5. Demos rarely work.

Result: When students watch demonstrations, they often don't see what we think they see.



Fagen
2003

5. Demos rarely work.

Result: Traditional demonstrations rarely change students' everyday ideas or knowledge structure.

Caveat: There are things you can do to make them work better.

Implication: Use demonstrations based on research, and ask students to predict the results of an experiment or to design an experiment.

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AAPT PHYSICS EDUCATION

6. Problem-solving ↛ understanding.

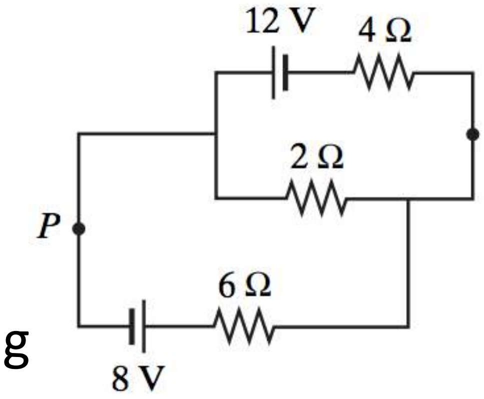
Result: Successfully solving traditional problems does not necessarily lead to conceptual understanding.

FCI studies (and others) show that students who perform well on traditional homework and exams lack basic conceptual understanding.

6. Problem-solving ⇏ understanding.

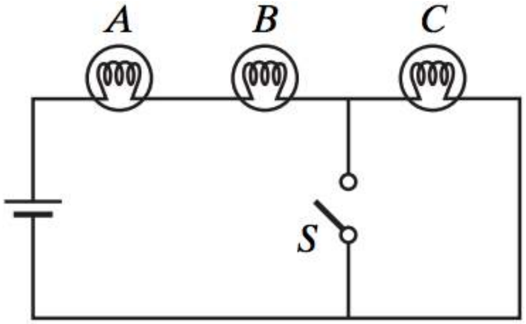
Example: Two exam questions in traditional course at Harvard: (Mazur 1997)

1. Calculate the current through the 2 Ω resistor and the potential difference between points P and Q.



~ 70%

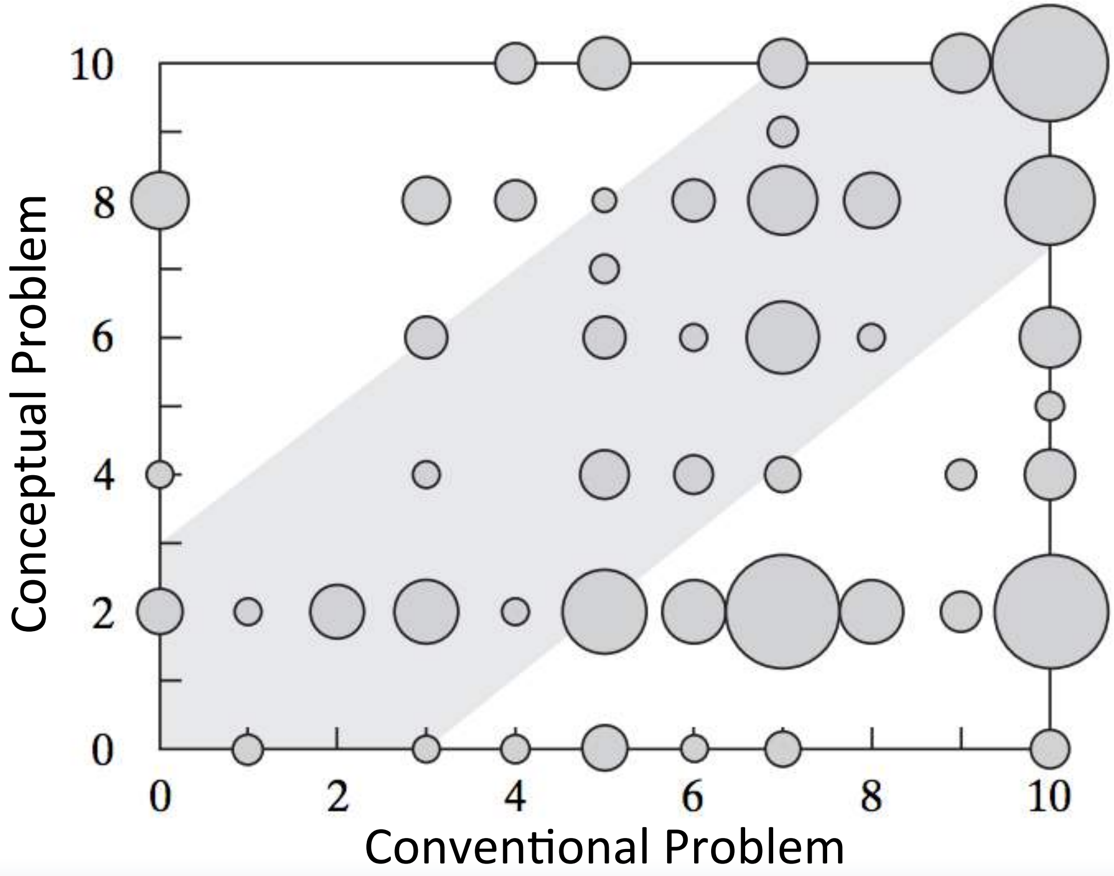
2. Predict whether each of the following will increase, decrease, or stay the same when the switch is closed:
   - Brightness of bulbs
   - Current through battery
   - Voltage drop across bulbs
   - Total power dissipated



~ 50%

6. Problem-solving ↛ understanding.

Example: Two exam questions in traditional course at Harvard: (Mazur 1997)



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Result: Successfully solving traditional problems does not necessarily lead to conceptual understanding.

Implication: Teaching students to solve problems is not sufficient.

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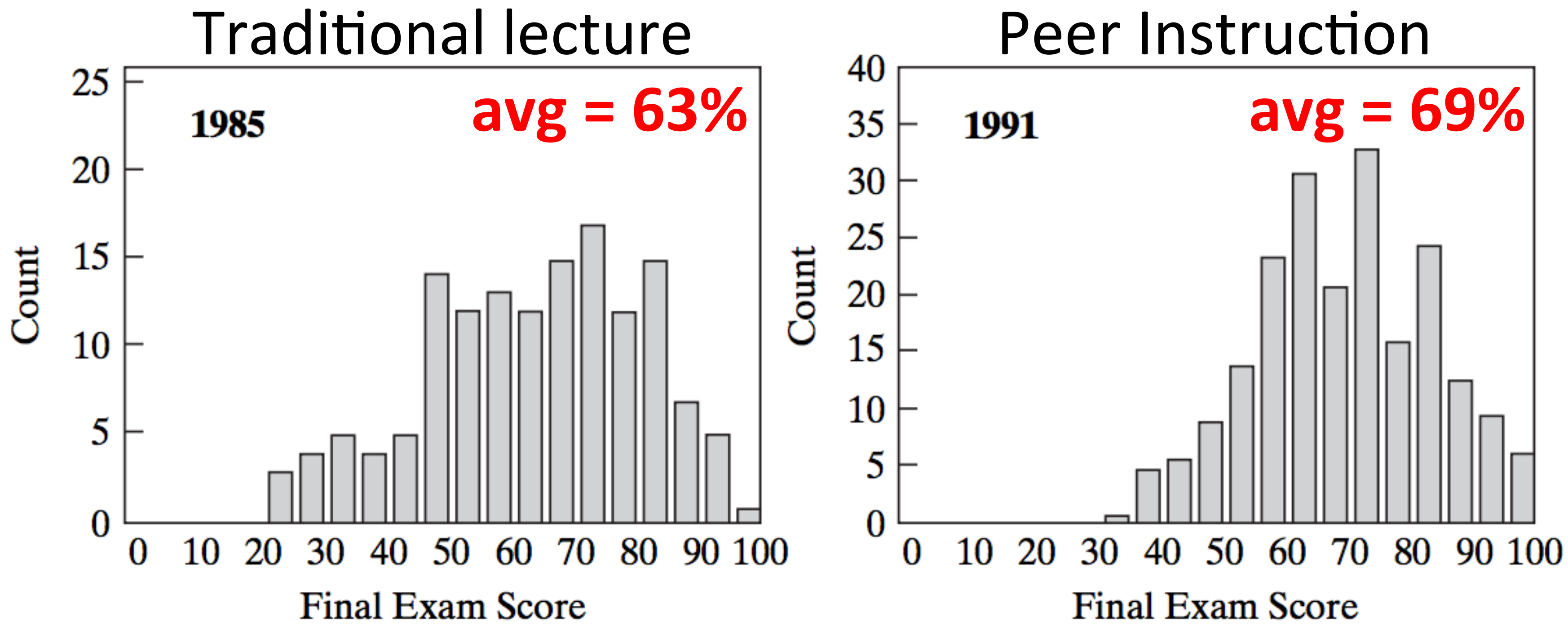
7. Understanding → problem-solving.

Result: Conceptual understanding can improve the ability to solve problems.

Students in courses using PER-based methods perform same or slightly better than students in traditional courses on traditional homework and exams.

7. Understanding → problem-solving.

Example: Same traditional final exams before and after implementing Peer Instruction (Mazur 1997)



(*a*) (*b*)

7. Understanding → problem-solving.

Result: Conceptual understanding can improve the ability to solve problems.

Implication: Devote more time to helping students develop conceptual understanding, even at the expense of spending time on problem solving.

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8. Most physics classes harm students' beliefs.

Assessing beliefs about physics & learning physics

- Colorado Learning and Attitudes about Science Survey (CLASS) (Adams et al. 2006)
- Maryland Physics Expectations survey (MPEX) (Redish et al. 1997)

Likert surveys:	Strongly Disagree … Strongly Agree

Example Statements:

- "In physics, it is important for me to make sense out of formulas before I can use them correctly."
- "Knowledge in physics consists of many disconnected topics."

Score = % agreement with experts

8. Most physics classes harm students' beliefs.

Assessing beliefs about physics & learning physics

- Typical physics course:
  - MPEX/CLASS scores decrease by 5-10%
  - True for both traditional and reformed courses!

8. Most physics classes harm students' beliefs.

Result: At the end of a typical physics course, students see physics as being:

- less connected to the real world,
- less coherent,
- less about sense making and reasoning,
- and more about rote calculation

than they did at the beginning of the course.

This is true even for reformed courses with large learning gains.

8a. …but not all of them do.

Assessing beliefs about physics & learning physics

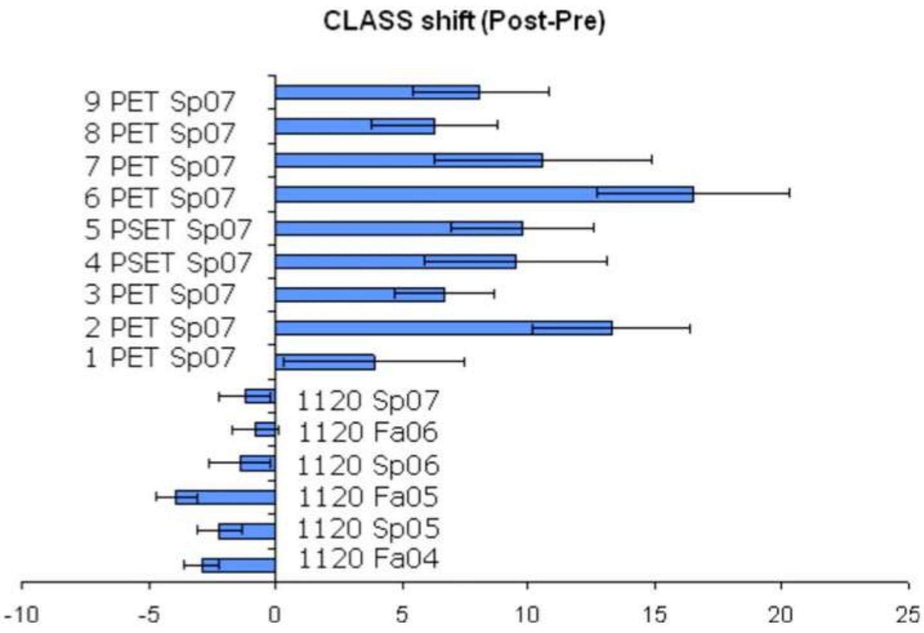
- MPEX/CLASS scores **decrease** by 5-10%:
  - Typical physics course (both traditional and reformed) (Redish 1997, Adams 2006, McKagan 2006, Kost 2009)
- MPEX/CLASS scores **stay the same**:
  - Courses with some attention to epistemology (Redish 1997, Finkelstein 2005, McKagan 2006, Kohl 2012)
- MPEX/CLASS scores **increase** by 5-10%:
  - Courses that are radically restructured to focus on model-building (Otero & Gray 2008, Lindsey 2012, Brewe 2009)
  - Courses with major focus on epistemology (Elby 2001, Redish & Hammer 2009)

8a. …but not all of them do.

Assessing beliefs about physics & learning physics

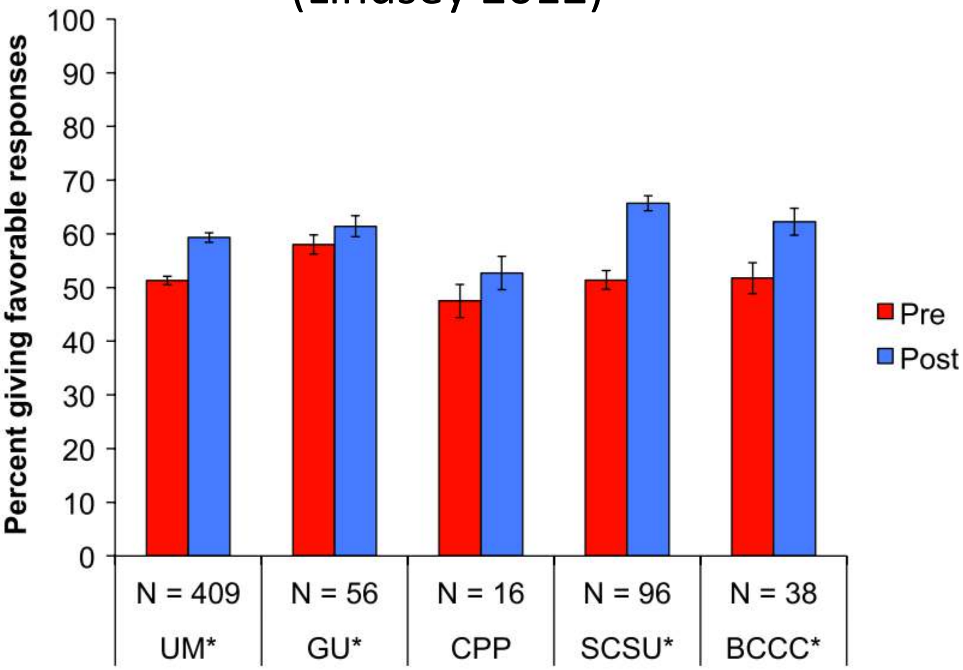
Physics in Everyday Thinking

(Otero & Gray 2008)



Physics by Inquiry

(Lindsey 2012)



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8. Most physics classes harm students' beliefs.

a. …but not all of them do.

Result: Typical physics courses lead students to think less like physicists than they did at the beginning. Changing the focus of the course can change this.

Implication: Use teaching methods that reward reasoning, questioning, sense-making, and connecting physics to the real world.

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9. Beliefs affect learning.

Result: Students' beliefs about learning physics affect their learning of physics.

Correlations between pre-test CLASS scores and conceptual learning gains

(Perkins 2004, Milner-Bolotin 2011, Wutchana 2011, Bodin 2012)

Implication: To improve your students' learning of physics, teach them what it means to learn physics.

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Result: Effective implementation and adaptation of PER-based methods requires understanding how these methods works.

Implication: Learn the rationale behind the teaching method you are using before you adapt it to fit your environment and goals.

Treat effective teaching as a difficult scientific problem and find resources to support you in solving this problem.