Educating Scientifically

Advances in Physics Education Research: Studies of Transforming Undergraduate Physics

Fermi National Accelerator Laboratory
16 May 2007

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Acknowledgements

**Physics faculty:**
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- Noah Finkelstein
- Kathy Perkins
- Steven Pollock
- Carl Wieman

**Postdocs:**
- Sam McKagan
- Linda Koch
- Laurel Mayhew

**Ph. D. students:**
- Wendy Adams
- Jack Barbera - U of N AZ
- Mariel Desroche
- Chris Keller
- Lauren Kost
- Pat Kohl - CO school of Mines
- Noah Podolefsky
- Chandra Turpen

**School of Ed members:**
- Valerie Otero
- Kara Gray
- Danielle Harlow - UCSB
- Bud Talbott III

This material is based upon work supported by the National Science Foundation under Grant No. REC 0448176, CAREER: Physics Education and Contexts of Student Learning. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the NSF.
Outline / Framing

• Brief overview of why, what, and how of PER
  – State of education
  – Why physicists?
  – Theoretical models & Educational practices

• Applying what we know
  – Implementing course transformation
  – Studying the process

• A sample of other CU research in PER

• New Directions
How important is education?

In March 2001, the U.S. Commission on National Security/21st Century on which I served warned that the crisis in scientific research and education is the second greatest threat facing American national security. In fact, the 14 bipartisan members unanimously agreed that the ‘inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine.’ The Commission went on to assert that only a nuclear or biological weapon released in an American city [is] a greater threat.

-Newt Gingrich, AEI open letter to Congress, May 2005
What’s our goal?

“By the Year 2000, United States students will be first in the world in mathematics and science achievement”

Goals 2000: Educate America Act

- originally from the 1989 National Gov’s Conference.
How are we doing: TIMSS

**Average Physics Performance of Advanced Science Students in All Countries**

<table>
<thead>
<tr>
<th>NATIONS WITH AVERAGE SCORES SIGNIFICANTLY HIGHER THAN THE U.S.</th>
<th>NATIONS WITH AVERAGE SCORES NOT SIGNIFICANTLY DIFFERENT FROM THE U.S.</th>
<th>NATIONS WITH AVERAGE SCORES SIGNIFICANTLY LOWER THAN THE U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NATION</td>
<td>AVERAGE</td>
<td>NATION</td>
</tr>
<tr>
<td>NORWAY</td>
<td>581</td>
<td>(AUSTRIA)</td>
</tr>
<tr>
<td>SWEDEN</td>
<td>573</td>
<td>(UNITED STATES)</td>
</tr>
<tr>
<td>(RUSSIAN FEDERATION)</td>
<td>545</td>
<td></td>
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<tr>
<td>(DENMARK)</td>
<td>534</td>
<td></td>
</tr>
<tr>
<td>(SLOVENIA)</td>
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<tr>
<td>(GERMANY)</td>
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</tr>
<tr>
<td>(AUSTRALIA)</td>
<td>518</td>
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<tr>
<td>(CYPRUS)</td>
<td>494</td>
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<tr>
<td>(LATVIA)</td>
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<td>SWITZERLAND</td>
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<td></td>
</tr>
<tr>
<td>GREECE</td>
<td>486</td>
<td></td>
</tr>
<tr>
<td>(CANADA)</td>
<td>485</td>
<td></td>
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<tr>
<td>FRANCE</td>
<td>466</td>
<td></td>
</tr>
<tr>
<td>CZECH REPUBLIC</td>
<td>451</td>
<td></td>
</tr>
</tbody>
</table>

International average = 501

http://timss.bc.edu
How are we doing: Harvard

• (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.

2. In the circuit 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%
~75%

From: Mazur (1997)
Rising Above Gathering Storm

Congressional charge (2005):
What are the top 10 actions, in priority order, that federal policymakers could take to enhance the science and technology enterprise so that the U.S. can successfully compete, prosper, and be secure in the global community of the 21st century?

1. 10,000 teachers, 10 million minds, and K–12 science and mathematics education
2. Science and engineering research
3. Best and brightest in science and engineering higher education
4. Incentives for innovation

Rising Above Gathering Storm

APRIL 24 2007:
House of Representatives passes H.R. 362, 10,000 Teachers, 10 Million Minds Science and Math Scholarship Act.

APRIL 26 2007:
Senate Passes S. 761, The America COMPETES Act
America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act

#4: INCENTIVES FOR INNOVATION
Overview of PER

• Far more to our classes than what has been traditionally evaluated
  – Our students are not learning what we believe them to
  – They are learning some things we would not expect

• Sub-field of physics education research has something to say about this
  – Tools for assessment
  – Models of student learning
  – Suggestions for curricula / approaches in class
What are our goals in class?

Novice
- Formulas & “plug ‘n chug”
- Pieces
- By Authority
- Drudgery

Expert
- Concepts & Problem Solving
- Coherence
- Independent (experiment)
- Joy

think about science like a scientist
think about education like a scientist

Adapted from: Hammer (1997) COGNITION AND INSTRUCTION (physics)
A possible “tipping” point

- Force Concept Inventory*
- Multiple choice survey, (pre/post)
- Experts (especially skeptics!)
  necessary (not sufficient) indicator of conceptual understanding.

* Hestenes, Wells, Swackhamer, Physics Teacher 20, (92) 141
Sample question

Looking down at a track (flat on table), a ball enters at point 1 and exits at point 2. Which path does it follow as it exits (neglect all friction)?
Force Concept Inventory

Take home message:

Students learn about 25% of the most basic concepts (that they don’t already know).

R. Hake, "...A six-thousand-student survey..." AJP 66, 64-74 ('98).
Attitudes & Beliefs:
Attitudes and Beliefs*

Assessing the “hidden curriculum” - beliefs about physics and learning physics

Examples:
• “I study physics to learn knowledge that will be useful in life.”
• “To learn physics, I only need to memorize solutions to sample problems.”

<table>
<thead>
<tr>
<th>CLASS categories</th>
<th>Shift (%) (“reformed” class)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real world connect...</td>
<td>-6</td>
</tr>
<tr>
<td>Personal interest........</td>
<td>-8</td>
</tr>
<tr>
<td>Sense making/effort...</td>
<td>-12</td>
</tr>
<tr>
<td>Conceptual.........................</td>
<td>-11</td>
</tr>
<tr>
<td>Math understanding...</td>
<td>-10</td>
</tr>
<tr>
<td>Problem Solving........</td>
<td>-7</td>
</tr>
<tr>
<td>Confidence.........................</td>
<td>-17</td>
</tr>
<tr>
<td>Nature of science.......</td>
<td>+5</td>
</tr>
<tr>
<td>Engineers: -12</td>
<td></td>
</tr>
<tr>
<td>Phys Male: +1</td>
<td></td>
</tr>
<tr>
<td>Phys Female: -16</td>
<td></td>
</tr>
</tbody>
</table>

(All ±2%)
why does this happen?
Trad’l Model of Education

Individual ➔ Instruction via transmission ➔ Content (e.g. circuits)
Built in to our classes?
I don't think you can teach physics very well anyway to people in that manner, by giving lectures on a big scale. I think it's hopeless.

Richard Feynman, 1918-1988
PER Theoretic Background

Individual

Instruction via transmission

Content (E/M)

Individual

Active construction

Content

Prior knowledge
actively engaging students is important
Consider *this* glass tube full of atoms, discharge lamp.

Expect that on average electrons will come out right hand end of tube but right as go in and some come out.
by actively engaging students...
red = trad, blue = interactive engagement

\[ <g> = \frac{\text{post-pre}}{100-\text{pre}} \]

R. Hake, "...A six-thousand-student survey..." AJP 66, 64-74 (‘98).
a contextual perspective

people's knowing / cognition is situated within social, cultural and historical contexts

what does this mean?
Meaning arises in context

Studying a procedure*

- arrange things into groups
- if you have to, go somewhere else due to lack of facilities
- do not overdue any endeavor
- a mistake is expensive
- manipulation of mechanisms is self-explanatory
- no foreseeable end to the necessity for this task

modest reframing of class context
U. Washington Tutorials
50 min/wk, 30 students, 1 grad TA
+ undergrad Learning Assistant
(Weekly prep + LA seminar)

Phys lecture
3-600 students
3 lectures/wk
(No lab)

Online HW System
CAPA or MP

Text
trad or PER based

Interactive Lectures
Peer Instruction,
pers. resp. system
Reconceptualize Recitation Sections

• Materials
• Classroom format / interaction
• Instructional Role


1. Three objects are at rest in three beakers of water as shown.
   a. Compare the mass, volume, and density of the objects to the mass, volume, and density of the displaced water. Explain your reasoning in each case.

<table>
<thead>
<tr>
<th>Object floats on top</th>
<th>Object floats as shown</th>
<th>Object sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Object floats on top" /></td>
<td><img src="image2" alt="Object floats as shown" /></td>
<td><img src="image3" alt="Object sinks" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Is ( m_{\text{object}} ) ( &gt; ) ( m_{\text{displaced water}} )?</th>
<th>Is ( m_{\text{object}} ) ( &gt; ) ( m_{\text{displaced water}} )?</th>
<th>Is ( m_{\text{object}} ) ( &lt; ) ( m_{\text{displaced water}} )?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explain.</td>
<td>Explain.</td>
<td>Explain.</td>
</tr>
</tbody>
</table>
Tutorial vs. Trad'l Recitation
CU Model of Teacher Prep

• Begin within physics department

• Learning Assistants:
  Use UG’s to implement PER-based materials
  – Model best-practices for all students
  – Improve education of all students
  – Increase likelihood students engage in teaching

• Improve content mastery of future teachers

Modifying Course Structure

Traditional Large Enrollment Course


R. Hake, "...A six-thousand-student survey..." AJP 66, 64-74 ('98).
red = trad, blue = interactive engagement

\[ \langle g \rangle = \frac{\text{post-pre}}{100-\text{pre}} \]

R. Hake, "...A six-thousand-student survey..." AJP 66, 64-74 ('98).
Attitudes & Beliefs

CLASS shifts (post-pre)
End of Term Survey
CLASS shifts (post-pre)

CU
Partly trad

CU
Reformed
(some attention to A&B)
perhaps success is not so simple...
Physics 1, 300+ students, Peer Instruction in lecture, and:

1: “Tutorials” (Sp04)  Tutorials
2: “Workbook” (Fa04)  Knight Workbook
3: “Traditional” (Sp05) Mostly traditional
Phys 1110 normalized gains

Tutorials

gain $<g>$ = .66 +/- .02
Phys 1110 normalized gains

Tutorials
Workbooks

gain $<g>$
$= .66 +/-.02$
$= .59 +/-.02$
Phys 1110 normalized gains

Tutorials
Workbooks
Traditional

gain $<g>$
$= 0.66 +/- 0.02$
$= 0.59 +/- 0.02$
$= 0.45 +/- 0.02$
Force Concept Inventory

red = trad, blue = interactive engagement

\[ \langle g \rangle = \frac{\text{post-pre}}{100-\text{pre}} \]

R. Hake, "...A six-thousand-student survey..." AJP 66, 64-74 ('98).
Strong indication: CURRICULA matters
Gender Studies
Gender difference on FCI scores

![Graph showing gender difference on FCI scores]

- Harvard trad
- Harvard partly trad

Comparison of pre and post scores.
Gender difference on FCI scores

[Graph showing gender difference on FCI scores for Harvard trad, Harvard partly trad, and CU partly trad groups, with pre and post comparisons.]
Gender difference on FCI scores

![Graph showing gender difference on FCI scores for Harvard tradition, Harvard partly tradition, CU partly tradition, and Harvard reformed. The graph includes pre and post comparisons.](image)

Lorenzo, Crouch, Mazur, AJP 74(2), 118-122 (2006).
Gender difference on FCI scores

![Bar chart showing gender differences on FCI scores for Harvard traditional, Harvard partly traditional, CU partly traditional, Harvard reformed, and CU reformed. The chart compares pre and post scores with error bars.]
Gender gap (BEMA)

Gender Gap in 1120 Pre and Post Test Scores

- Fall 04
- Spring
- Fall 05
- Spring 06
- Fall 06

Symbols:
- * indicates a significant difference
- Pretest and Posttest
Transformed Pedagogy: PER-based techniques necessary but not sufficient

Learning by Teaching:
the LA Story
Learning gains for LAs and TAs

- Enrolled Students
- Learning Assistants
- Teaching Assistants (1st time)

LAs leave at incoming TA level!
Lasting Impacts (preliminary)
Longitudinal Studies
How Junior level E&M fair on BEMA?

After completing Jr Level E/M (3310 or 3320)
Only students who took Phys 2 (1120) without Tutorials
Impact of Tutorials

Red bins: students who had taken Freshman physics (1120) *with* Tutorials (~2 years prior)
Impact of LA experience

Beige: students who had been 1120 LAs
Strong indication: CONTEXT matters
actively engaging is important
what people know affects what they learn
contexts shape what students learn (content and beliefs)
teaching is effective for instructor learning
Conclusions

• Educational practice is a researchable endeavor
  – We can make systematic progress
  – Imperative to include physicists

• Possible to achieve dramatic repeated results

• CU model strongly couples:
  – Reform and research
  – Education and physics

• Sustaining & Scaling reforms is possible
  – Requires theoretical framing
  – Both CONTENT and CONTEXT matter

It’s not about our teaching, it’s about student learning
Fin

Much more at: per.colorado.edu
CLASS - last 6 terms (1110)

CLASS Shift (Post-Pre) Phys 1110

-15  -10  -5   0   5   10

Sp04  (PER faculty)  Pre - 68
Fa04   Pre - 66
Sp05   Pre - 63
Fa05   Pre - 70
Sp06   Pre - 60
Fa06   Pre - 68

Overall
CLASS - last 6 terms (1120)

CLASS Shift (Post-Pre) 1120

-10 -5 0 5 10

Fa04 (PER faculty)  Pre - 70
Sp05 (PER faculty)  Pre - 67
Fa05                Pre - 61
Sp06                Pre - 63
Fa06 (PER backup)  Pre - 62

Overall
CLASS F06: Comparing students & LA’s
CLASS and learning gains

Phys 1110 Fa03 - PER instructor

Beliefs (pre / post) vs. learning gain

Low learning gain <---------> high learning gain

Affect: Tutorials (Phys 1120)

Phys 1120: fraction "not negative"

Exams 25% “Tutorial-like” questions
The *spinach model* of educational reform?

- Students (sometimes) find Tutorial useful
- But more rarely find them enjoyable.
Affect: Tutorials (Phys 1110)

Phys 1110: fraction "not negative"

(Missing data for 2 “trad” terms)
Affect: Tutorials (Phys 1110)

Phys 1110: fraction "not negative"

Much more variation - instructor effects?

(Missing data for 2 “trad” terms)
Impact on different pretest populations: "high starters" 50<pre<93%

normalized gain for high pretest

Semester (% of class in this pool)

Tut course
Trad Recit

Course (1) (2) (3)
Impact on different pretest populations: "low starters" pretest $\leq$ 12.5%

![Normalized gain for low pretest](image)

<table>
<thead>
<tr>
<th>Semester</th>
<th>Course</th>
<th>(% of class in this pool)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S04 (23%)</td>
<td>Tut course</td>
<td>Trad Recit</td>
</tr>
<tr>
<td>F04 (20%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S05 (22%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>