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

A Crisis in US Education

U.S. ranks:
21 out of 30 in science
25 out of 30 in math

- PISA 2006

International Rankings (science)

A Crisis in US Education

U.S. ranks:
24 out of 30 in science
31 out of 30 in math

- PISA 2009

International Rankings - Science

Challenges in US Education

1 Million more STEM grads needed over the next decade

100,000 more STEM educators

We advocate doubling the number of bachelor degrees in physics to address critical national needs including K-12 education, economic competitiveness, energy, security, and an informed electorate.

How might this happen?
- Better preparation
- Retention

Traditional Model of Education

A Wakeup Call

- Force Concept Inventory*
- Multiple choice survey (pre/post)
- Experts (especially skeptics!)

A necessary (not sufficient) indicator of conceptual understanding.

* Hestenes, Wells, Swackhamer, Physics Teacher 20, (92) 141, 1992

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

Students learn less than 25% of the most basic concepts (that they don't already know).
Can high school students learn more from interactive techniques adapted from university physics courses?

Typical Classroom (?)

Students debate a concept test

Overview

• Transforming the classroom
  – Concept tests/Pear instruction
  – In-class activities/tutorials

• Quantum Simulations
  – Lasers (!)
  – Matter waves

• Quantum Interpretations

Many PER curricular innovations

Question 2

Concept Tests
Arguments against using concept tests

- Eats up time
  - Important ideas can be complex
- Discussion easy in small classes
  - We/they don’t always know they need to ask questions
- Students may resist
  - But perhaps only initially…
- Extra effort for teachers
  - Question banks available if you want to try!

Tutorials in Introductory Physics

Reconceptualize Classroom Learning

- Materials
- Classroom format / interaction
- Instructional Role

Tutorial Materials

Hands-on, Inquiry-based, Guided, Research-based

Assignment 11B: Buoyancy

<table>
<thead>
<tr>
<th>Note</th>
<th>Tutorial session</th>
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1. These 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.

   - Object floats on top
   - Object floats as shown
   - Object sinks

   - Is $m_{object}$ > $m_{displaced}$? Explain.
   - Is $V_{object}$ < $V_{displaced}$? Explain.
   - Is $\rho_{object}$ < $\rho_{water}$? Explain.

Trad’l Classroom vs. Tutorials

Trad’l Classroom: Hands-on, Inquiry-based, Guided, Research-based

Tutorials: ComPADRE Digital Library, mostly online resources, some print materials, and teachers in Physics and Astronomy Education.

Extra effort for teachers:
- Question banks available if you want to try!
Socratic Dialogue

Impact on different pretest populations: "low starters" pretest <=12.5%

Impact on different pretest populations: "high starters" 50<pre<93%

Long Term Impacts
Upper-Division Physics Majors – BEMA Scores

Grade in course

* Upper-Division E&M (I or II)

Tutorials

No Tutorials

Had intro E&M with Tutorials


It’s not about our teaching, it’s about creating environments that support student learning

http://phet.colorado.edu
Modern Physics for Engineers

“I think quantum mechanics is an interesting subject.”

New Modern Physics Curriculum

- Expose students to ideas regarding interpretive themes from the historical development of QM.
  - Complementarity/wave-particle duality
  - Wave function collapse
  - Entanglement/non-locality

- Present canonical experiments on foundations of QM.
  - Single-quanta experiments
  - Distant, correlated measurements

- Introduce contemporary topics in quantum information theory.
  - Computing, cryptography, etc...

Modern Physics Course Materials

Modern Physics for Engineers

“I think quantum mechanics is an interesting subject.”
Double-Slit Experiment
(photons or electrons)

1. A plane wave is incident on the double slit.
2. Waves spread out behind each slit.
3. The waves interfere in the region where they overlap.
4. Bright fringes occur where the amplitude cancels through the viewing screen.

Double-Slit Experiment with Single Electrons (1989)

- [Realist] Each electron is a tiny particle that went through one slit or the other.
- [Matter-Wave] Each electron went through both slits and interfered with itself.
- [Agnostic] We can’t say what the electron is doing between being emitted and detected.

When not being observed, an electron in an atom exists at a definite but unknown position at each moment in time.
"The probabilistic nature of quantum mechanics is mostly due to the limitations of our measurement instruments."

"I think quantum mechanics is an interesting subject."

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**Student Reflections**

"I entered Physics 3 with a bitter taste in my mouth. Yet, some fragment of my mangled ego compelled me to continue down the path I was on. I have always found physics to be the most intriguing subject, and I was not about to let one class ruin it. I approached Physics 3 as the deal breaker: if this class was like its predecessor, then maybe mechanical engineering was a more apt major. […] Through the course, the almost magical results quantum mechanics attained reassured me that I am in the correct major. The teaching style in conjunction with the material made quantum physics attainable. I am not sure if it was the teaching that rejuvenated my passion or the material itself; either way I welcomed back my old friend, physics, with open arms and anticipation."

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**Questions?**

Much more at:  
[per.colorado.edu/cts](http://per.colorado.edu/cts)  
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