

Active Learning & Quantum Simulations in the Classroom
 KITP Conference, Santa Barbara
 March 2, 2013
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PER.COLORADO.EDU

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American Association of Physics Teachers
 Physics Teacher Education
 AMERICAN INSTITUTE OF PHYSICS
 APS
 MATH + SCIENCE
 HHMI HOWARD HUGHES MEDICAL INSTITUTE

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)

Country	Mean Test Score
Finland	563
Hong Kong China	542
Canada	534
Chinese Taipei	532
Estonia	531
Japan	531
New Zealand	530
Australia	527
Netherlands	525
Luxembourg	522
United States	488

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

Country	Mean Test Score
Shanghai China	580
Finland	555
Hong Kong China	550
Singapore	545
Japan	540
China	535
New Zealand	530
Canada	525
Australia	520
Netherlands	515
Chinese Taipei	510
Germany	505
Luxembourg	500
United Kingdom	495
South Korea	490
Denmark	485
France	480
Poland	475
Belgium	470
United States	465
United Arab Emirates	460
Algeria	455
Italy	450
Spain	445
Portugal	440
Sweden	435
Austria	430

Challenges in US Education

1 Million more STEM grads needed over the next decade
 100,000 more STEM educators

HELP WANTED PROJECTIONS of JOBS and EDUCATION REQUIREMENTS Through 2018

Life and Physical Sciences Occupations (2005-2018)
 Computer and Mathematical Science Occupations (2005-2018)

APS/AAPT Doubling Initiative Mission Statement (2007)

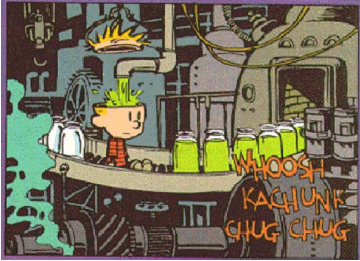
We advocate **doubling the number of bachelor degrees** in physics to **address critical national needs** including **K-12 education**, economic competitiveness, energy, security, and an informed electorate.

How might this happen?

- Better preparation
- Retention

Traditional Model of Education

Content $\xrightarrow[\text{transmission}]{\text{Instruction via}}$ Individual



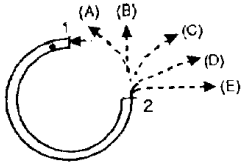
A Wakeup Call

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

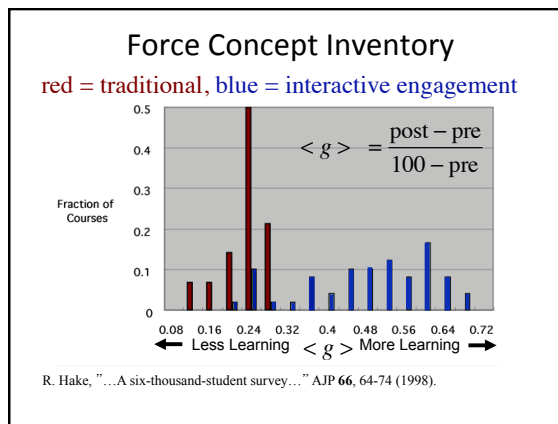
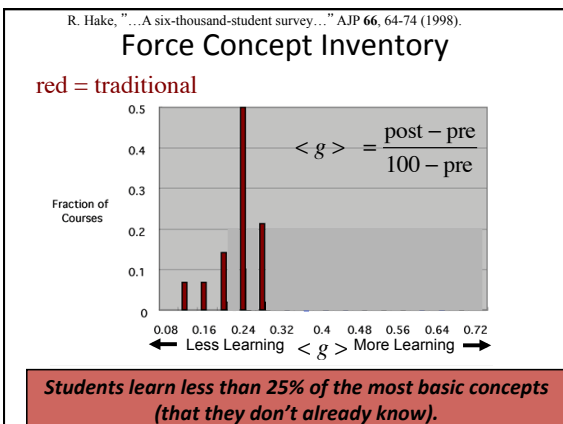
A necessary (not sufficient) indicator of conceptual understanding.

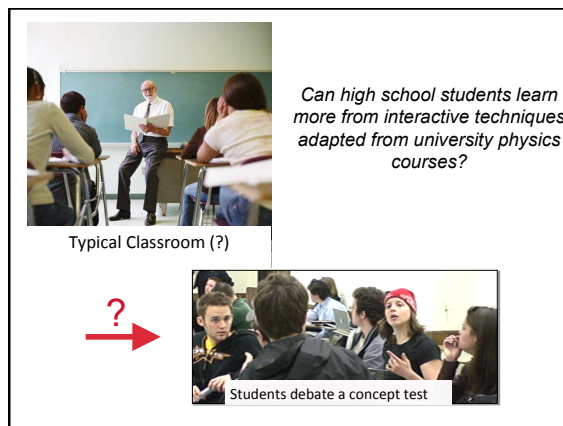
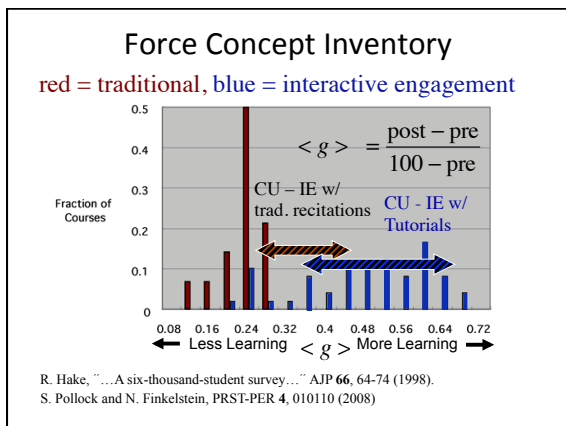
* Hestenes, Wells, Swackhamer, Physics Teacher 20, (92) 141, 1992

Sample question

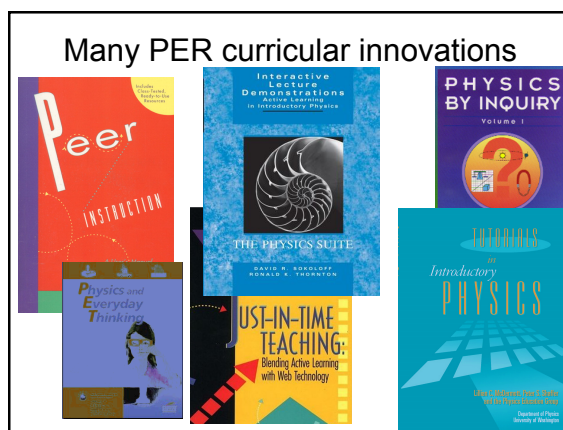


Looking down at a track (flat on table), a ball enters at point 1 and exits at point 2. Which path does it follow as it exits (neglect all friction)?





- ### Overview
- Transforming the classroom
 - Concept tests/Peer instruction
 - In-class activities/tutorials
 - Quantum Simulations
 - Lasers (!!)
 - Matter waves
 - Quantum Interpretations



PER User's Guide

Evidence-based resources for teaching physics

Methods & Materials What is PER? Assessment Connect with PER Users Why use PER Methods?

Which method is best?
It depends... Select criteria that match your needs below:

- Research Validation
- Type of Method
- Course Level
- Instructional Setting
- Coverage
- Topic
- Instructor Effort Req.
- Resources Needed
- Student Skills Dev.

Showing 54 out of 54 evidence-based teaching methods

Peer Instruction (Concept Tests, ConceptTests) **Detailed Implementation Guide available**

Level: Intro College Calc-based, Intro College Alg-based
Setting: Large Lecture (Can be adapted for: Small Class)
Coverage: Many topics with less depth - Requires...
Effort: Low - (If suitable ConceptTests are...)
Resources: Multiple choice questions and polling method. A.
Skills: Conceptual understanding of physics content; Connecting conceptual and mathematical understanding.

PHET Interactive Simulations (PHET Simulations)

Level: Intro College Calc-based, Intro College Alg-based
Setting: Large Lecture, Recitation, Lab, Small Class
Coverage: Few topics with great depth. Many topics with less depth.
Effort: Low
Resources: Access to computers either in or outside of class
Skills: Conceptual understanding of physics content; Enjoyment of physics; Connecting conceptual and mathematical understanding.

Teaching with Clickers (personal response systems, PRS, electronic voting systems, classroom response systems)

Concept Tests

Consider *this* glass tube full of atoms, discharge lamp

Expect that on average

- more photons will come out right hand end of tube
- less come out right
- same number as go in
- none will come out.

Question 2

Peer Instruction

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 11M: _____ Name _____
Buoyancy _____ Tutorial section _____

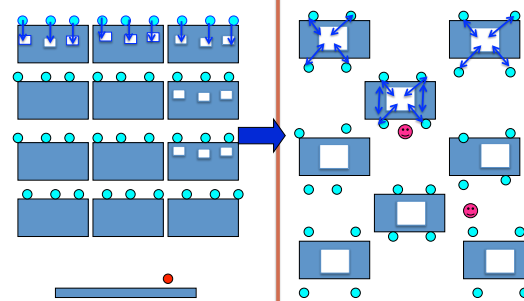
- Three objects are at rest in three beakers of water as shown.
 - Compare the mass, volume, and density of the objects to the mass, volume, and density of the displaced water. Explain your reasoning in each case.

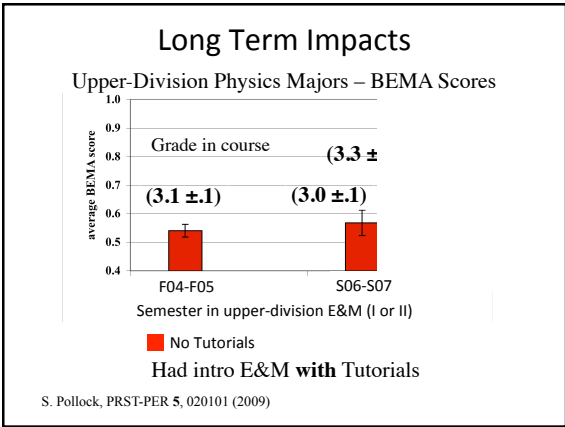
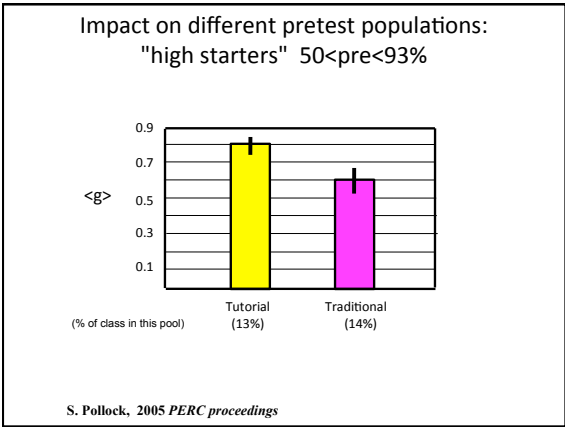
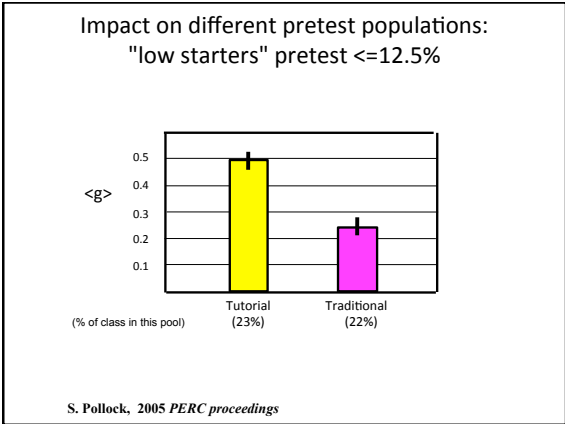
 Object floats on top	 Object floats as shown	 Object sinks
Is $m_{\text{object}} < m_{\text{displaced water}}?$ Explain	Is $m_{\text{object}} < m_{\text{displaced water}}?$ Explain	Is $m_{\text{object}} < m_{\text{displaced water}}?$ Explain

The screenshot shows the comPADRE website interface. At the top, there's a navigation bar with links for 'Explore the Collections', 'Events', 'Partners', 'People', 'Collaborate', 'Community Services', and 'Contact Us'. Below this is a 'Featured Collection' section for 'MINOCULUS'. The main content area is divided into sections for 'For Students' (including 'The Nucleus', 'Did You Know?', 'Physics to Go', 'Physics Career Resource', 'Physics Classroom', 'Physics to Go', 'Physics to Go') and 'For Teachers' (including 'Physics Front', 'Physics to Go', 'PSIC', 'Physics to Go'). There are also sections for 'For Faculty - General' and 'For Faculty - Courses'. The right sidebar contains 'Participate!', 'Collaborators', and 'Sponsors and Partners'.

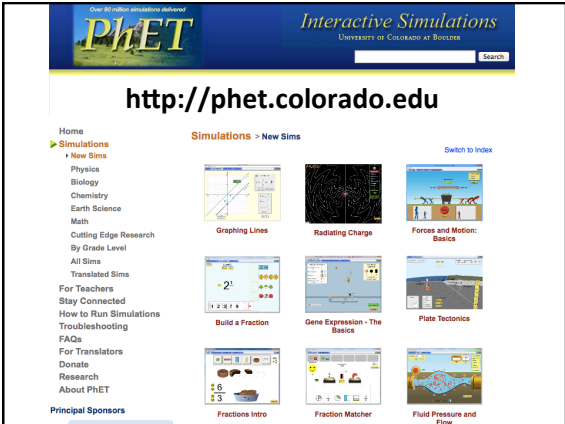
The screenshot shows the Quantum Exchange website. It features a search bar at the top and a navigation menu. The main content area is titled 'Welcome!' and includes a 'Browse Quantum Topics' list with items like 'Approximation Techniques', 'Bound State Systems', 'Entanglement and Quantum Information', 'Foundations and Measurement Theory', 'General', 'Multi-particle Systems', 'Probability, Waves, and Interference', 'Scattering and Continuum State Systems', and 'Spin and Finite Dimensional Systems'. There are also sections for 'Featured Materials', 'Recent Discussions', and 'This Just In...'.

Trad'l Classroom vs. Tutorials





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



Over 60 million simulations delivered

PhET Interactive Simulations
UNIVERSITY OF COLORADO AT BOULDER

<http://phet.colorado.edu>

Home
 • Simulations
 New Sims
 Physics
 Motion
 Sound & Waves
 Work, Energy & Power
 Heat & Thermo
 • Quantum Phenomena
 Light & Radiation
 Electricity, Magnets & Circuits
 Biology
 Chemistry
 Earth Science
 Math
 Cutting Edge Research
 By Grade Level
 All Sims
 Translated Sims
 For Teachers
 Stay Connected
 How to Run Simulations
 Troubleshooting

Simulations > Physics > Quantum Phenomena

Photoelectric Effect
 Quantum Tunneling and Wave Packets
 Quantum Bound States
 Quantum Wave Interference
 Lasers
 Neon Lights & Other Discharge Lamps
 Fourier: Making Waves
 Simplified MRI
 Models of the Hydrogen Atom

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 General Chemistry
 • Quantum Chemistry
 Earth Science
 Math
 • Cutting Edge Research
 By Grade Level
 Elementary School
 • Middle School
 • High School
 • University

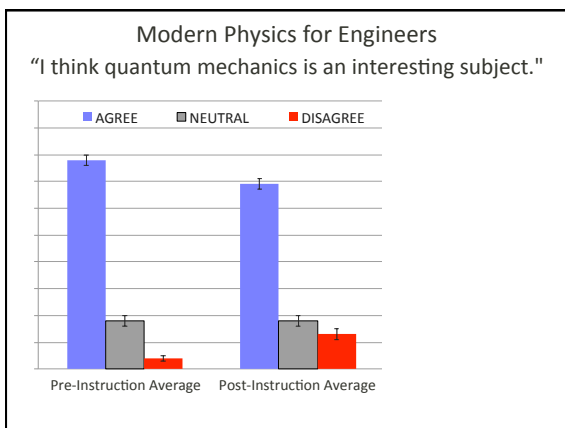
Lasers

Create a laser by pumping the chamber with a photon beam. Manage the energy states of the laser's atoms to control its output.

Download 1.822 kB
 Run Now!
 Embed Version: 4.08 (change log)

TEACHING RESOURCES
 Main Topics
 • Laser
 • Photon Beams
 • Quantum Mechanics

Sample Learning Goals
 • Describe how absorption and spontaneous and stimulated emission work, and explain the requirements for each to occur.
 • Describe how a laser works.



- ### 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

Home About the Course Browse Materials QM Sims Associated Research Download All Materials

Modern Physics Course Materials

Please contact Charles Baily if you would like to be notified when these materials are updated.

Are you using these materials? Please contact us if you plan to use all or part of these course materials for your own modern physics course. If you have already used these materials, please fill out a short survey (~5 min.) about your experience. Your valuable feedback will help us understand where and how these materials are being used, and ways they might be improved.

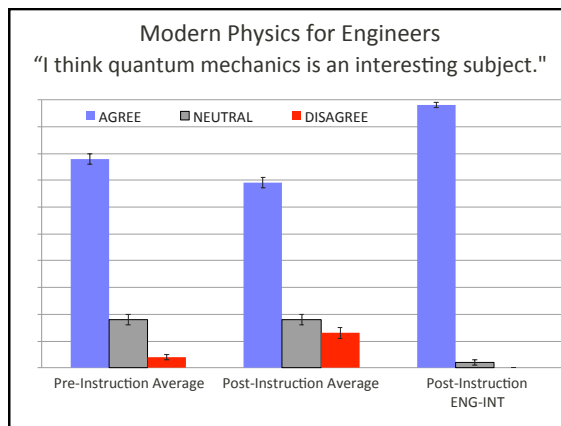
Modern Physics is the third semester in our three-semester sequence of introductory physics courses. It comes in two flavors at CU: a course for engineering students (PHYS 2130), and one for physics majors (PHYS 2170). These course materials have been used in both environments.

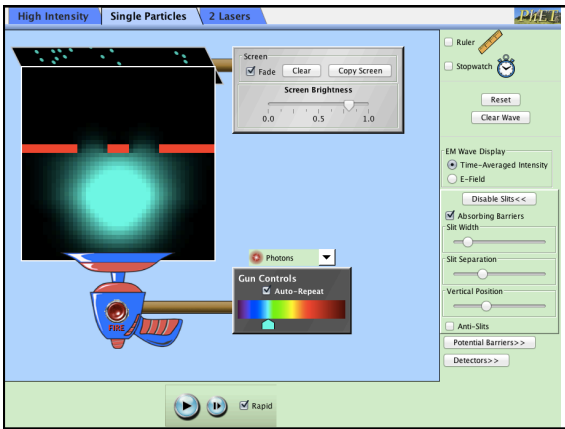
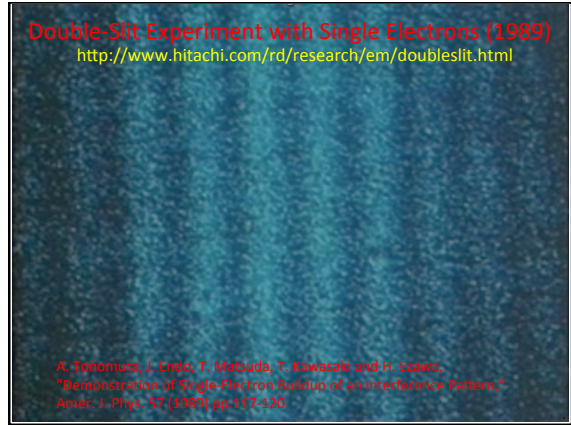
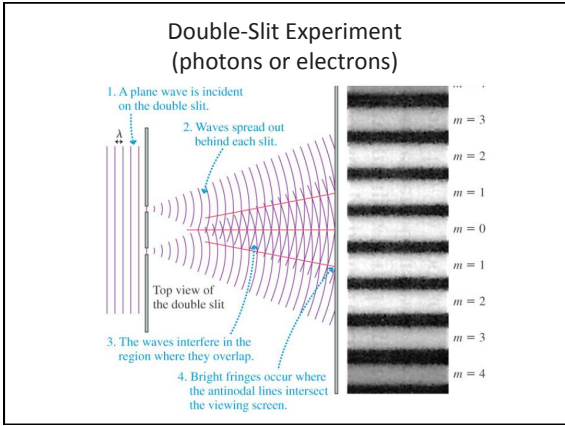
These materials were first developed and used by Carl Wieman, Kathy Perkins, and Sam McKagan in Fall 2005 and Spring 2006. They have seen significant additions and improvements over the years (see below), and the latest versions include the following topics:

- Special relativity
- Photoelectric effect
- Atomic spectra and lasers
- Bohr and deBroglie models
- Stern-Gerlach, entanglement & single-quanta experiments
- Matter waves and the Schrödinger equation
- Tunneling, α -decay, STM's
- Hydrogen atom and molecular bonding
- Conductivity, semiconductors, BEC

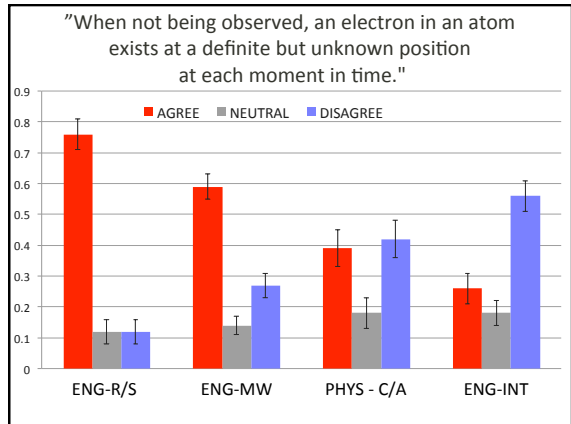
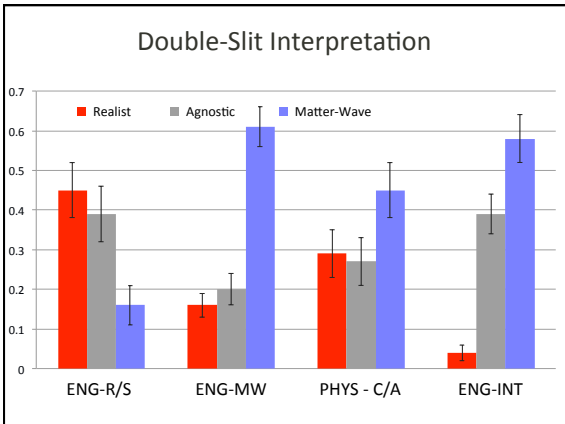
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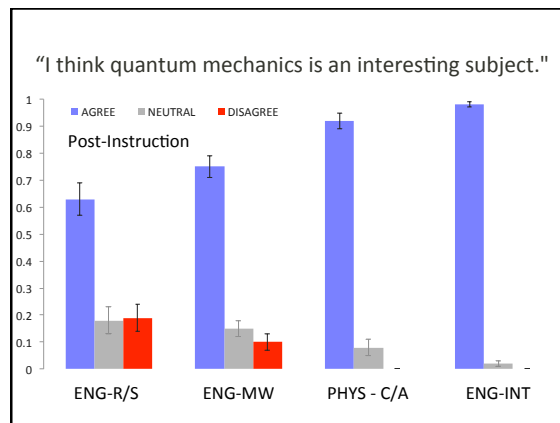
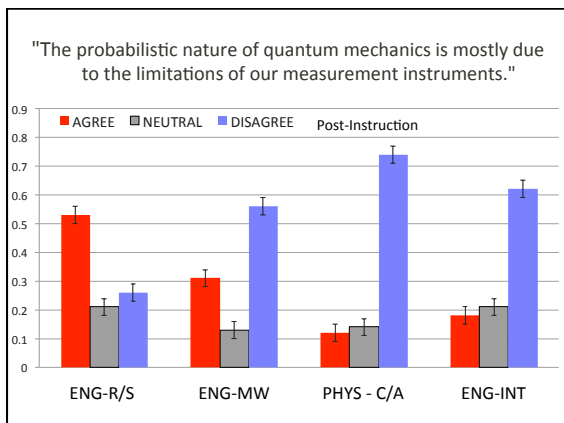
Materials for other courses
 Classical Mechanics
 Electrostatics
 Electrodynamics
 Quantum Mechanics
 Advanced Lab





- **[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.





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. [...] Throughout 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.**"

Questions?

Much more at:



per.colorado.edu/cts

per.colorado.edu/ModernPhysics
stemclickers.colorado.edu



phet.colorado.edu

perusersguide.org

www.compadre.org/quantum

www.falstad.com/mathphysics.html