Physics Education Research

From theory to practice in introductory physics courses

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University of Cincinnati

Why are we here?

Your standard introductory physics class, filled with obnoxious-to-most-other-students pre-meds. The professor is in the middle of a long lecture on simple harmonic motion, when one student snaps, and shouts "What is the point of learning this?"

The lecturer not skipping a beat, simply says "It saves lives," and goes back to the derivation.

After a few minutes, the same student shouts out, "How will this help save lives?"

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Your standard introductory physics class, filled with obnoxious-to-most-other-students pre-meds. The professor is in the middle of a long lecture on simple harmonic motion, when one student snaps, and shouts "What is the point of learning this?"

The lecturer turns around, simply says "It saves lives," and goes back to the derivation.

After a few minutes, the same student shouts out, "How will this help save lives?"

To which the professor replies: "It keeps idiots like you out of medical school."

Outline

Goal: to stimulate discussion about teaching strategies and techniques

- Pre-test
- Motivating questions
- Principles from physics education research (PER) that can help boost understanding of physics
- Add to your toolkit (some already used in UC physics courses!)
  - Interactive Lecture Demonstrations/Questions
  - Tutorials (in recitations)
  - Real Time Data Acquisition Laboratories
- Conclusions
- Learn more
  - From the experiences of other research universities
  - From PER literature

Pre-test

Which of the following is correctly spelled?

a) Cinncinati

b) Cincinnati

c) Cincinnatey

d) Sinsinnati

e) Cincinatti

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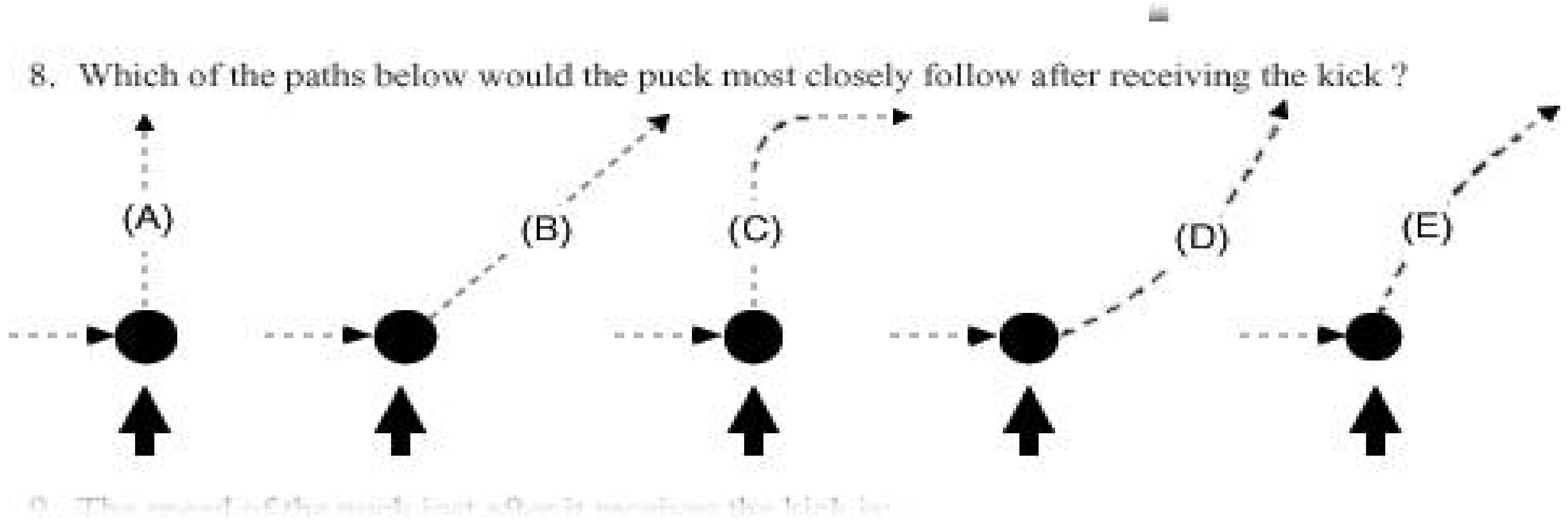


8. Which of the paths below would the puck most closely follow after receiving the kick ?

Consciousness-raising: physics is hard

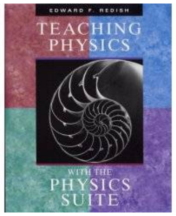
- Force Concept Inventory, D. Hestenes et al., *The Physics Teacher* **30** (1992) 141, is a widely-used test of Newtonian conceptual thinking. Source of previous problem.
- Authors suggest that 60% is threshold for effective problem solving
- Selected results, Arizona (in %) :
  - Regular high school: 48±16 (N=612)
  - Honors high school: 56±19 (N=118)
  - AP high school: 57±18 (N=33)
  - Univeristy: 63±18 (N=139)
- "..few physicists can recall having ever believed, let alone having overcome, any of the misconceptions, though research has established unequivocally that everyone has them before learning physics."
- **To teach physics (or anything for that matter) well, one must remember what it was like not to know physics.**

Questions worth asking

- How can we engage students in active learning?
- How can we coordinate material among different components of a single course (lectures, labs, recitations, homework, exams)?
- How can we connect physics with other disciplines, e.g., engineering, computer science, or other natural sciences?
- How should we choose what content to cover in our courses?
- How can we give students a favorable attitude toward the subject of physics?
- **How can we most effectively teach students to think as physicists?**

Physics Education Research

- PER addresses the problems of physics education by studying how students learn physics and what teaching techniques are most effective
- Many PER folks have physics Ph.D.'s and came from traditional physics research backgrounds before migrating later in their career
  - Closer in culture and organization to physics departments than education dep'ts
- At least 36 U.S. universities have websites for PER groups (http://www.physics.umd.edu/perg/homepages.htm)
- Wide body of PER literature
  - American Journal of Physics (AAPT)
  - Physics Education (IOP)
  - Physical Review Special Topics - Physics Education Research (APS)
  - The Physics Teacher (AAPT)
- The "Jackson" of PER, and the source for much of this talk, is *Teaching Physics with the Physics Suite*, E. F. Redish, 2003, available free at http://www2.physics.umd.edu/~redish/Book/



PER in use at peer institutions

- A committee of Stanford physics faculty is exploring how to adapt our introductory courses
- As a research assistant for the committee, I contacted other universities to learn about the approaches they take to introductory physics
    - MIT
    - U. Oregon
    - U. Illinois
    - U. Maryland
    - U. Washington
    - RPI
    - Tufts
    - Dickinson
    - Harvard
- All of these universities incorporate PER-related techniques. Some have adopted substantial changes that affect many faculty (Dickinson, RPI, Illinois, MIT), while others have adopted changes in a more piecemeal fashion, often spearheaded by one or a few professors.

Redish's Cognitive Principles

- **What matters most in a course is what students actually do**
  - Implication: Get students to actively engage in physics as much as possible. Physics is not a spectator sport!
  - But students can actively work with equipment without learning much physics
- Five principles:
  - Constructivism: People build knowledge by connecting to existing knowledge.
  - Context: People think differently depending on context.
  - Change: It's hard to learn something we don't almost already know.
  - Individuality: Individuals show significant variation in how they learn.
  - Social learning: For most individuals, learning is most effectively carried out through social interactions.

Wells's golden rules of teaching (abridged)

- Remember the opportunity cost: if you teach X you can't teach Y.
- Other people (especially non-physicists) don't necessarily learn best the way you learn best.
- The "best way to learn" does not exist: good teachers use a diversity of methods.
- Never invent what you can steal (and adapt) instead!

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Interactive Lecture Demos

ILD Steps

Present the question, clarify any unclear wording.

Poll the students.

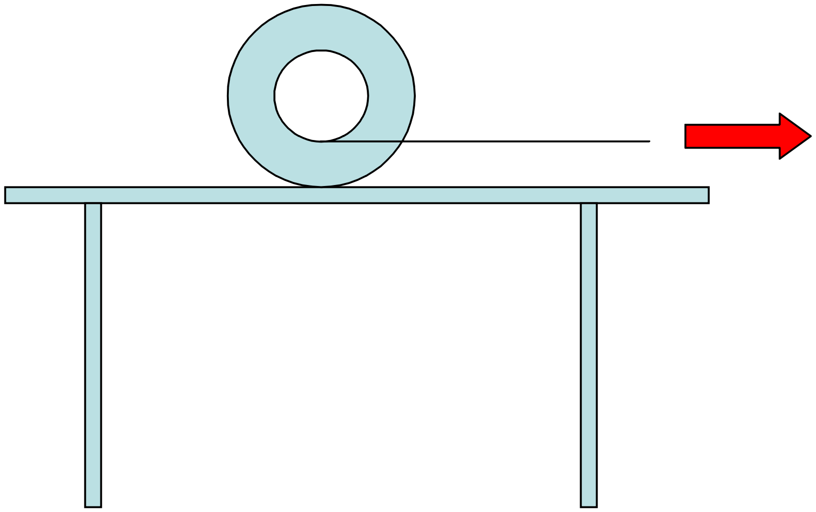
Peer discussion; poll again.

Perform experiment.

Explain the results / answer questions.

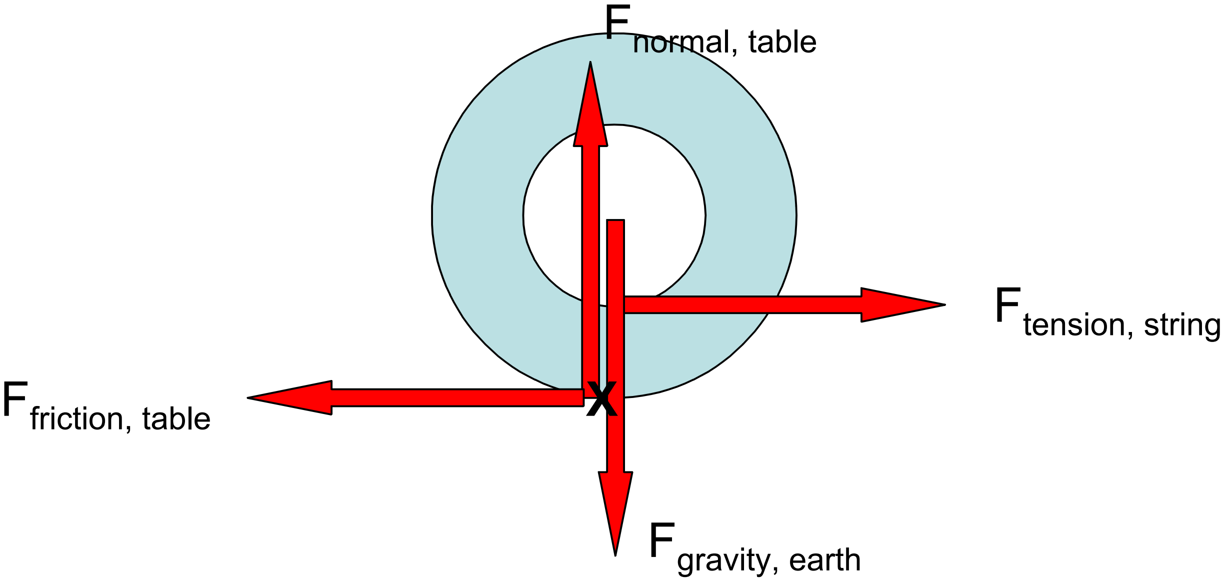
When the string is pulled slowly and horizontally to the right, what happens?

1) Spool rolls to the right.
2) Spool slides to the right.
3) Spool rolls to the left.
4) Something else.



Interactive Lecture Demos

Explanation



- Find the torque with reference point at the point of contact with the table.
- The friction, normal, and gravity forces contribute 0 torque, while the tension force contributes a negative (clockwise) torque, causing the spool to roll to the right.
- If the angle of the string is raised so that the tension force is directed through the point of contact with the table, there will be no torque and the spool will slide without rolling.
- If the angle of the string is raised beyond that point, the string exerts positive (CCW) torque, and the spool rolls left.

Interactive Lecture Demos

- Traditional lecture: one-way communication, from instructor to students, with no feedback
- ILD's are a way of prompting students to think, (not just copy from the chalkboard) and discuss ideas with their peers
- In large lectures, polling is usually done with a Personal Response System ("clickers"). These are low-cost (~$10-30 new on amazon.com) and can send responses directly to a laptop via a USB-connected radio receiver, allowing for rapid display of results.
- Interaction in lectures does not require a demonstration; conceptual PRS questions also stimulate peer discussion.

Interactive Lecture Demos, questions

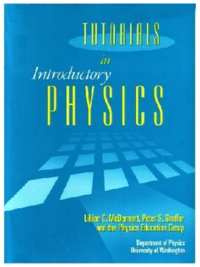
- Advantages of ILD's
  - Promote active thinking over passive absorption.
  - Stimulate peer discussion.
  - Provide feedback to professor about student comprehension.
  - In a survey of 24 MIT faculty who teach the intro course, "..there is remarkably consistent agreement on the usefulness of the PRS." (J. Belcher, email 31 Mar 2008)
- Disadvantages of ILD's
  - Take more time to cover the same topic. Doing too many in a single lecture may leave students bored.
  - Technical operation represents an initial barrier.
- Who uses them: Tufts, U. Oregon, U. Illinois, U. Maryland, MIT, Harvard, Stanford ☺

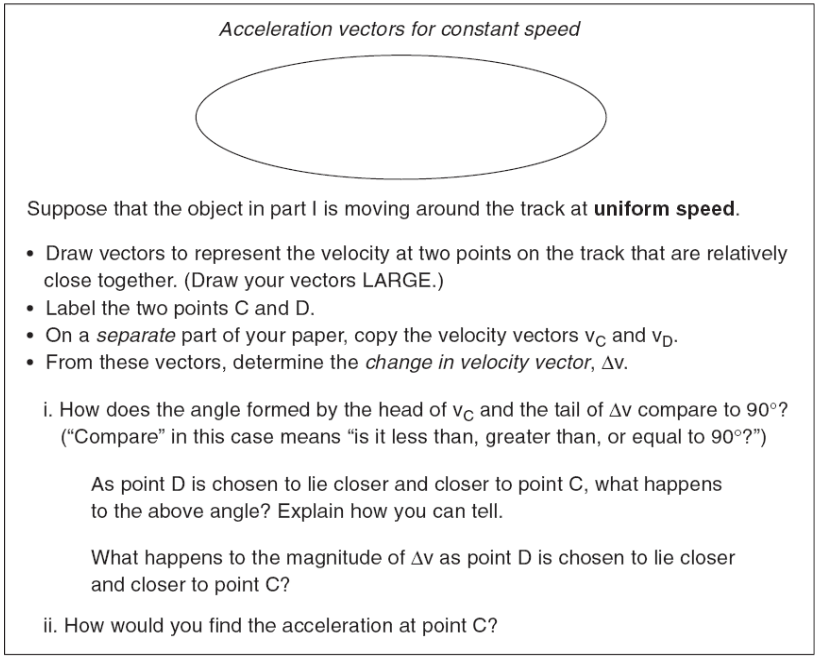
Tutorials

- Traditional discussion section: teaching assistant (usually a graduate student) works through problems on the board, pausing occasionally to answer questions or to give students a chance to try a problem on their own
- Tutorial recitation:
  - Students work on problems in teams
  - Teaching assistants give guidance, not lectures
  - Focus is on problem-solving strategies rather than extended calculations
  - Critical distinction: the size of the working group (~3 in workshop, ~20 in traditional)
- Implementation
  - Solutions may be written on marker boards or on individual worksheets
    - If using marker boards, be sure to have "sign-off" sheets so that the TA checks the group's work and ensures that group members are taking turns holding the marker (thanks to D. Applegate for this tip).
    - Advantage of individual worksheets is that students have a written record. In the case of marker boards, you may choose to post solutions on-line.
  - In a team of more than 3, someone is always separated from the writing board by one person.
  - Group work requires reconfiguration of the seats/tables in the classroom

Tutorials

Example of a Tutorial problem from *Tutorials in Introductory Physics*, L. McDermott and P. Shaffer, 1998.





Acceleration vectors for constant speed

Suppose that the object in part I is moving around the track at **uniform speed**.

- Draw vectors to represent the velocity at two points on the track that are relatively close together. (Draw your vectors LARGE.)
- Label the two points C and D.
- On a *separate* part of your paper, copy the velocity vectors v_C and v_D.
- From these vectors, determine the *change in velocity vector*, Δv.

i. How does the angle formed by the head of v_C and the tail of Δv compare to 90°? ("Compare" in this case means "is it less than, greater than, or equal to 90°?")

As point D is chosen to lie closer and closer to point C, what happens to the above angle? Explain how you can tell.

What happens to the magnitude of Δv as point D is chosen to lie closer and closer to point C?

ii. How would you find the acceleration at point C?

- Designed to address common misconceptions, build conceptual understanding, and strengthen problem-solving skills.
- Though carefully-written problems as in McDermott and Shaffer are ideal, even with more conventional problems students benefit from collaborative problem-solving in the tutorial method.

Tutorials

Practice tutorial: Exercise 1.31, *The Art of Electronics 2nd Ed.*, P. Horowitz and W. Hill, 1989.

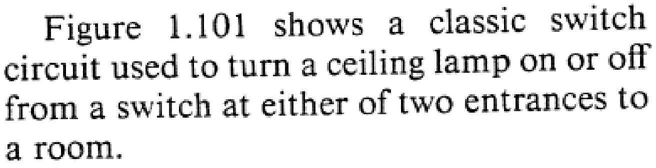


Figure 1.101 shows a classic switch circuit used to turn a ceiling lamp on or off from a switch at either of two entrances to a room.

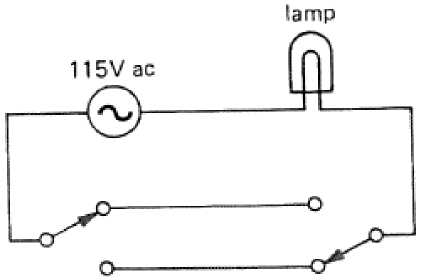
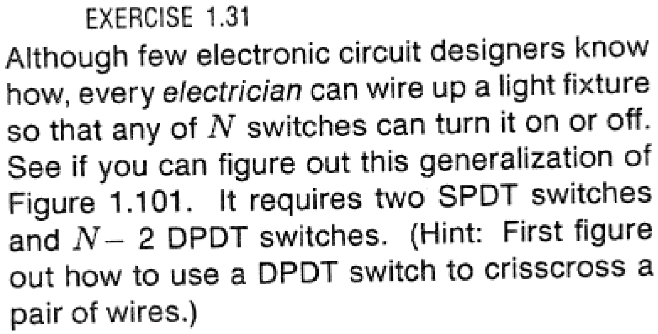


Figure 1.101. Electrician's "three-way" switch wiring.



EXERCISE 1.31

Although few electronic circuit designers know how, every *electrician* can wire up a light fixture so that any of N switches can turn it on or off. See if you can figure out this generalization of Figure 1.101. It requires two SPDT switches and $N - 2$ DPDT switches. (Hint: First figure out how to use a DPDT switch to crisscross a pair of wires.)

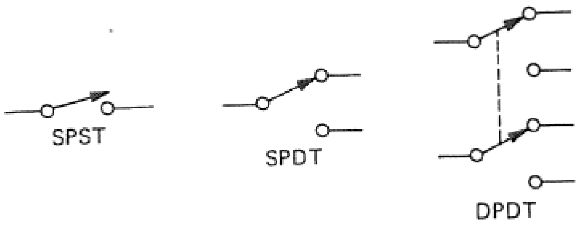


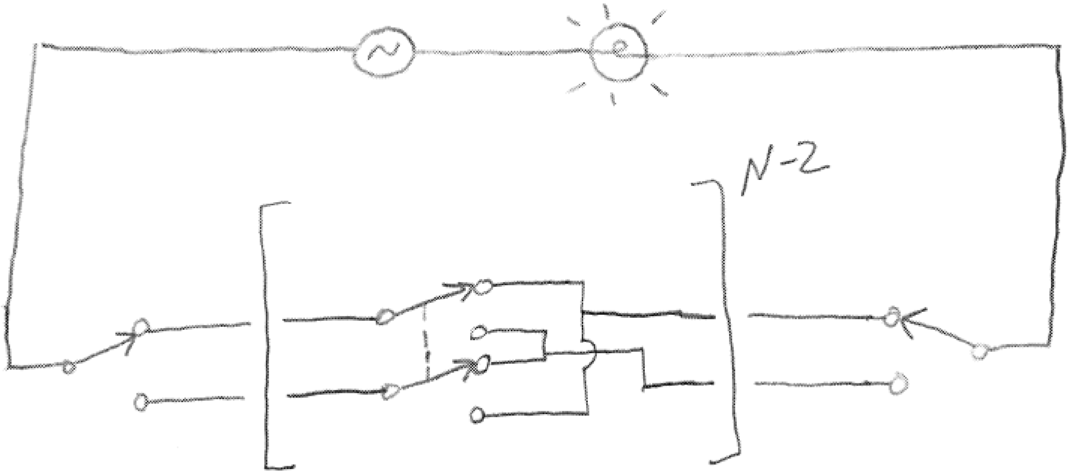
Figure 1.98. Fundamental switch types.

Directions:

1) Work in group of no more than 3.
2) Appoint one scribe.
3) Show work and solution on easel paper.
4) Sign Tutorial Progress sheet, and get TA signature when finished.

Tutorials

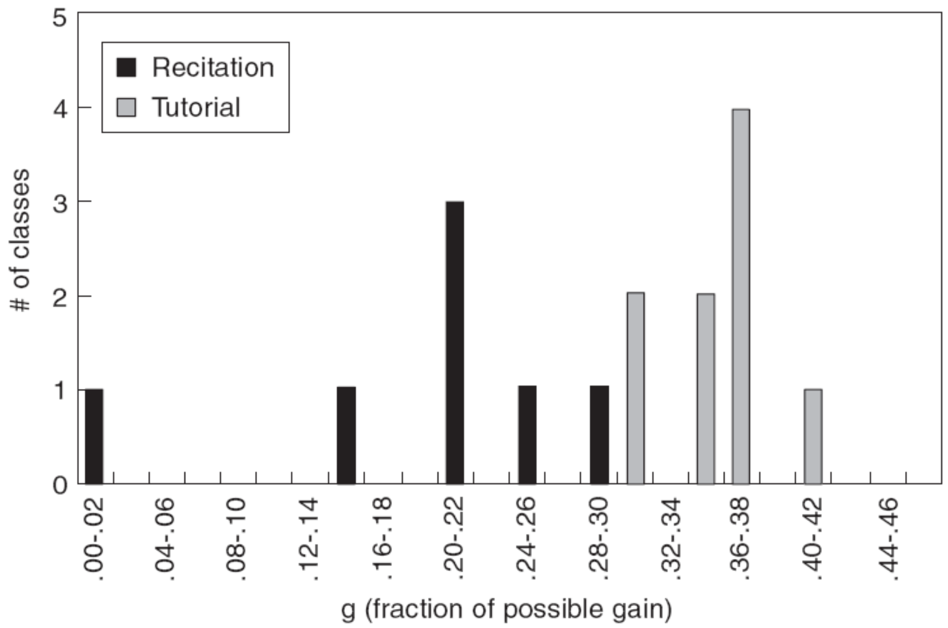
Practice tutorial solution.



Tutorials

- Advantages of tutorials
  - Students are more actively engaged during the recitation.
  - Students teach each other.
  - Students get to know each other socially.
- Disadvantages of tutorials
  - Likely misconceptions must be targeted in problems since they are not broadcast in mini-lectures.
  - Takes more time to cover same amount of material (increased recitation time is one solution).
  - Requires more guidance of teaching assistants from the course instructor (writing problems, at a minimum).

Tutorials



Source: TPPS p. 151

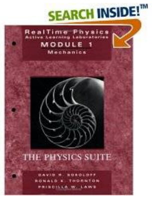
Figure 8.3 Fraction of the possible gain attained by engineering physics students at the University of Maryland in classes taught with traditional recitations (dark) and tutorials (light).

- Who uses them: U. Washington, U. Maryland, U. Illinois, U. Colorado

Real time data acquisition labs

- Required:
  - Traditional lab equipment (carts, pulleys, masses)
  - Sensors (of position, force, pressure, voltage, etc.)
  - Interface to computer
  - Guidance to **predict, observe, and explain**—in written and verbal form (level of direction may vary)
- Goal: help students make the connection among physical, graphical, and algebraic representations of a phenomenon (e.g., period of a pendulum, force in a collision, pressure of a sound wave, etc.)
  - This skill is one that physicists take for granted but which many non-physicists struggle with.
  - Real time data acquisition lets students see graphs created of a physical quantity.
- Lab manual (electronic version available for modifications):

  RealTime Physics, D. Sokoloff, R. Thornton, P. Laws, 2004.



Real time data acquisition labs

- Real time data acquisition lab setups (short videos)
  - Newton's 2nd law, Vernier (start at 1:55)
  - Ball toss, Vernier (start at 1:15)
  - U. Md. Tutorial (http://www.physics.umd.edu/perg/abp/abptutorials/implmnt.htm)
- Main advantage over traditional labs: allow students to focus on physics, rather than data collection and organization
- Useful for teaching how to model the relationship between two variables—independent, directly proportional, inversely proportional, etc. (part of the the "hidden curriculum" of physics)
- Black box nature of sensors requires "psychological calibration" to understand how they work

Real time data acquisition labs

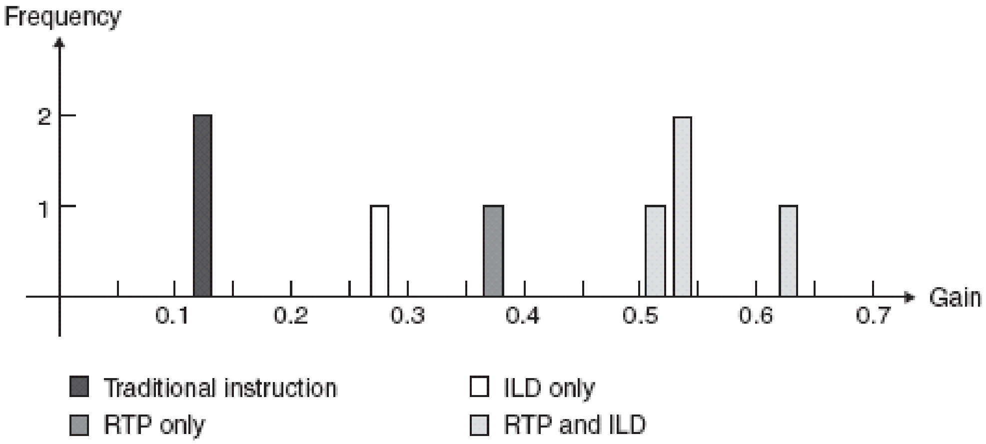


Figure 8.13 Fractional gains on the FMCE in five different colleges and universities that used fully traditional instruction, or traditional lectures with RTP, or RTP and ILDs ($N = 1000$) [Wittmann 2001].

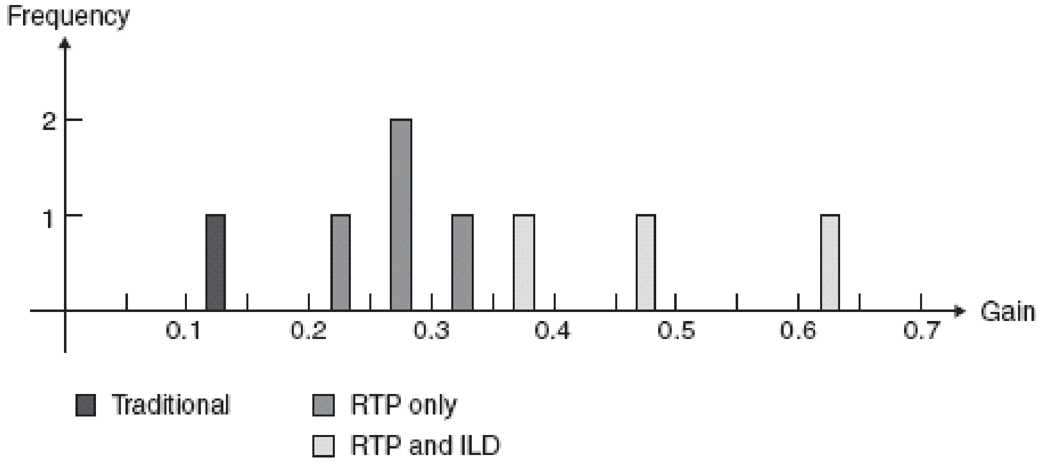


Figure 8.14 Fractional gains on the ECCE at four different colleges and universities that used fully traditional instruction, or traditional lectures with RTP, or RTP and ILDs ($N = 797$) [Wittmann 2001].

- Who uses them:
  - Tufts
  - U. Oregon
  - MIT
  - Dickinson
  - U. Maryland
  - U. Illinois
  - RPI
  - NC State

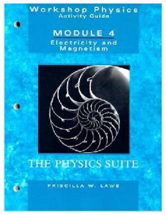
Source: TPPS p. 168-169

Conclusions

- PER helps answer the questions we asked at the outset; here is my interpretation (by no means definitive!):
  - *Engage students in active learning?* Put students in the driver's seat: focus on what they are doing, not just what they are hearing/seeing.
  - *Coordinate material among different components of a course?* Examine the same concept from many perspectives. (Also organizational work required!)
  - *Connect physics with other disciplines?* Follow constructivist theory and place physics in a context students can relate to (one example: http://www.princeton.edu/integratedscience/curriculum/freshman/course/)
  - *Choose what content to cover?* Put priority on physics and problem solving over data collection and long calculations.
  - *Give students a favorable attitude toward physics?* Build students' confidence that they can do physics and that physics makes sense.
  - ***Most effectively teach students to think as physicists?*** **Use a variety of research-tested strategies.**
- No one has a monopoly on excellent teaching practices, so stay on the lookout for more good ideas!

Other PER tools

- JITT, Just In Time Teaching (100 institutions), web-based assignments that give feedback to instructors, www.jitt.org
- Interactive Simulations (U. Illinois, U. Colorado), http://research.physics.uiuc.edu/per/ie.html, http://phet.colorado.edu/new/index.php
- *Workshop Physics*, aka Studio Physics (MIT, Dickinson, RPI, NC State), text by P. Laws



- Video analysis in lab (U. Illinois, Dickinson), http://research.physics.uiuc.edu/PER/Coder/, http://www.lsw.com/videopoint/
- Socratic computer tutoring, not sure if there is any academic research behind it, so maybe not PER-endorsed, but a cool new tool, http://www.masteringphysics.com

Learn More

- The Bible of PER techniques: *Teaching Physics with the Physics Suite*, E. F. Redish, 2003.
- An uber-bibliography: http://www.physics.umd.edu/perg/tools/rl.htm
- Sample ILD's: *Interactive Lecture Demonstrations*, D. R. Sokoloff and R. K. Thornton, 2001.
- Guide to interactive techniques in lecture: *Peer Instruction: A User's Manual*, E. Mazur, 1997.
- Research-based tutorial problems, developed at U. Washington: *Tutorials in Introductory Physics*, L. C. McDermott and P.S. Shaffer, 1998.
- Computer-based labs: *Real Time Physics*, D. R. Sokoloff, R. K. Thornton, and P. Laws, 1995.
- Take a free (NSF-funded) Chautauqua summer course (~3 days)
  http://physics.dickinson.edu/~wp_web/wp_resources/wp_workshops.html or http://uoregon.edu/~sokoloff/chaut1.htm
- How one university adopted widespread reform in its intro courses: http://research.physics.uiuc.edu/PER/Course_Revisions.html

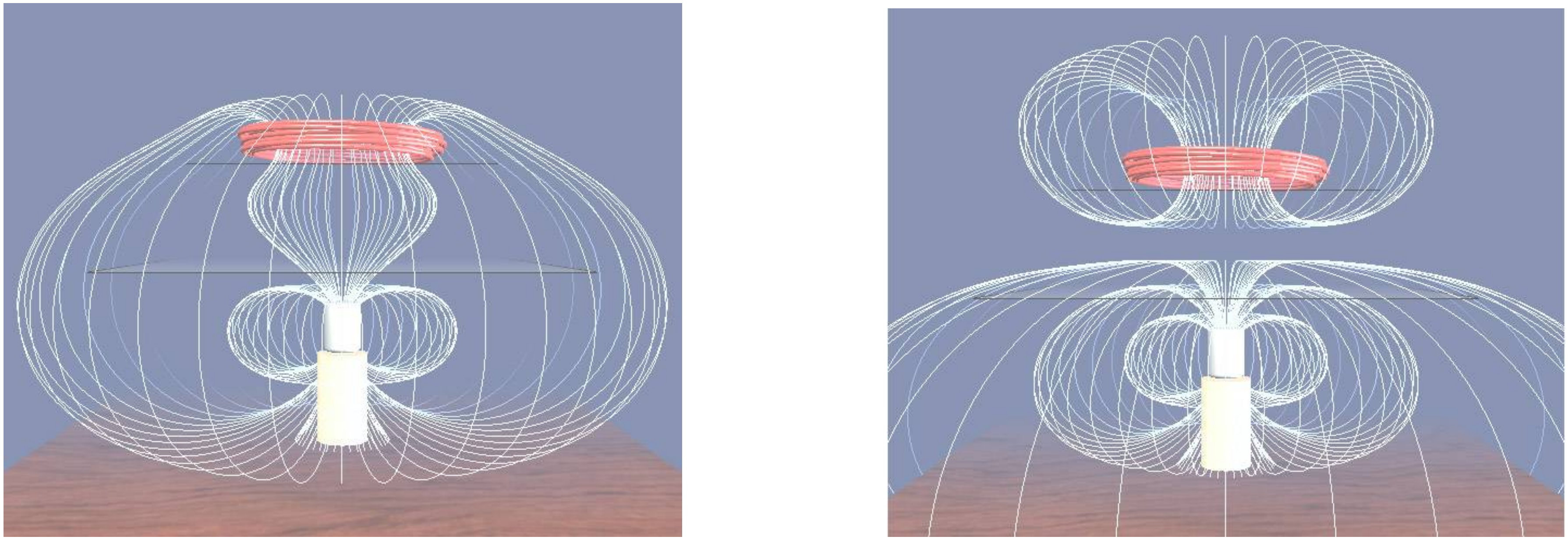
Backup slides

Sample Interactive Lecture Question

Which statement below is true?

- 1. The left figure corresponds to the field configuration when the coil was attracted to the magnet, and the right figure to when the coil was repelled by the magnet.
- 2. The left figure corresponds to the field configuration when the coil was repelled by the magnet, and the right figure to when the coil was attracted to the magnet.

(with permission from J. Belcher, MIT)



Sample Interactive Lecture Question

Answer:

1. The left figure represents attraction and the right repulsion. The fields on the left exert a tension on the coil that pulls down, the fields on the right exert a pressure on the coil that pushes upward.