



**INNOVATIONS IN TEACHING
INTRODUCTORY PHYSICS**

**LESSONS FROM PHYSICS
EDUCATION RESEARCH (PER)**

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SASS

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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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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

- What's the problem?
- How PER can help you solve it.
- Add to your toolkit
 - Interactive Lecture Demonstrations/Questions
 - Tutorials (in recitations)
 - Real Time Data Acquisition Laboratories
- How to learn more

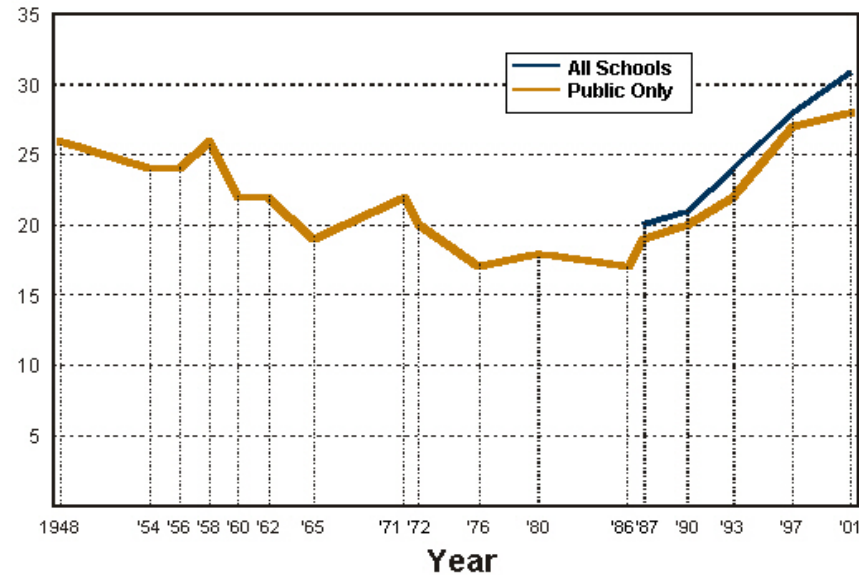
PHYSICS HAS A POPULARITY PROBLEM

- Q: What fraction of American high school seniors have taken physics?

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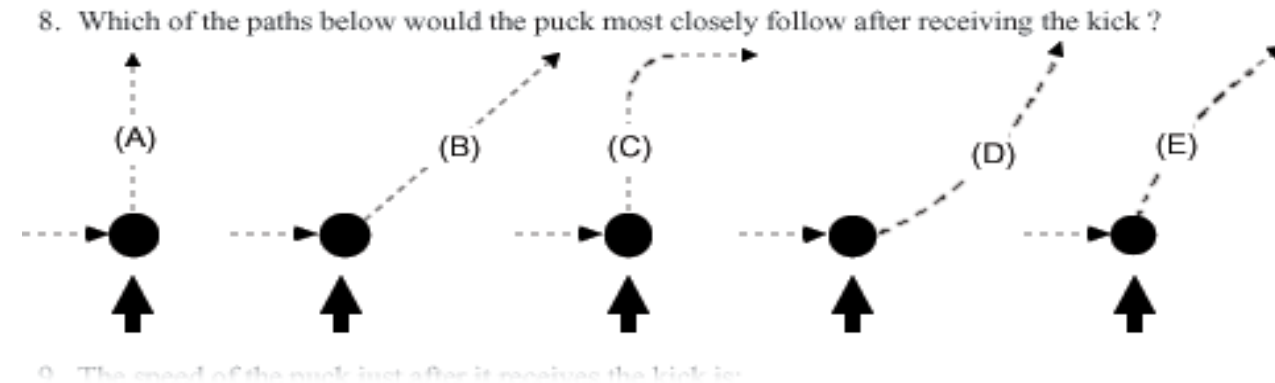
% of seniors who have taken physics



(source: AIP)

PHYSICS HAS A BELIEF PROBLEM

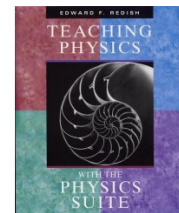
Force Concept Inventory, D. Hestenes et al., *The Physics Teacher* **30** (1992) 141, is a widely-used test of Newtonian conceptual thinking.



- 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)
 - University: 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.”

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/>



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.
 - 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)

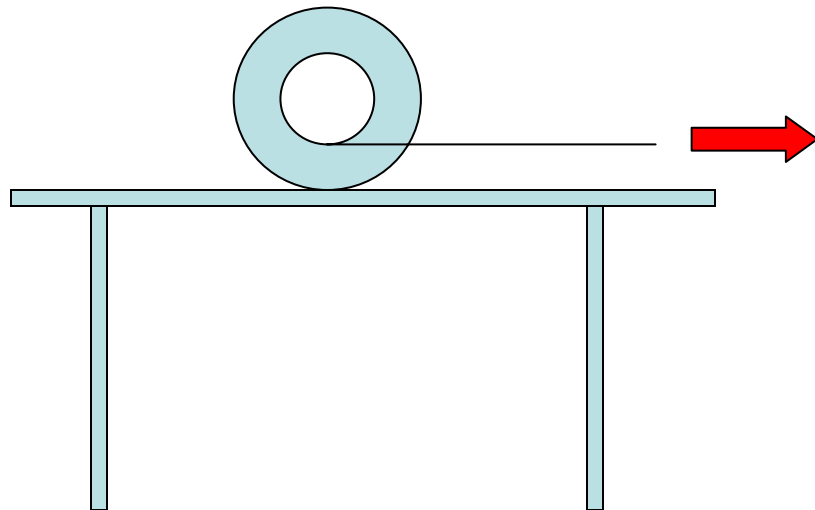
- Remember the opportunity cost: if you teach X you can't teach Y.
- Other people (especially non-physicists) don't necessarily learn best the way you learn best.
- The “best way to learn” does not exist: good teachers use a diversity of methods.
- Never invent what you can steal (and adapt) instead!



INTERACTIVE LECTURE DEMOS

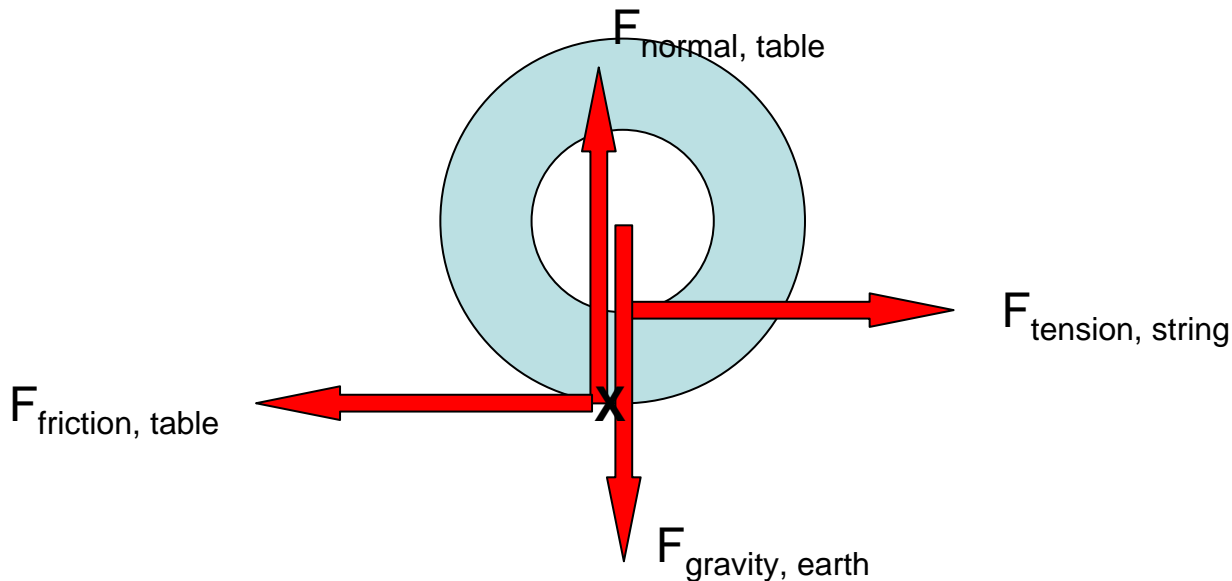
When the string is pulled horizontally to the right, what happens?

- 1) Spool rolls to the left.
- 2) Spool rolls to the right.
- 3) Not enough information to determine.



INTERACTIVE LECTURE DEMOS

EXPLANATION



- Find the torque with pivot 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
- Steps
 - Present the question, clarify any unclear wording.
 - Poll the students.
 - Peer discussion; poll again.
 - Perform experiment.
 - Explain the results / answer questions.

INTERACTIVE LECTURE DEMOS, QUESTIONS

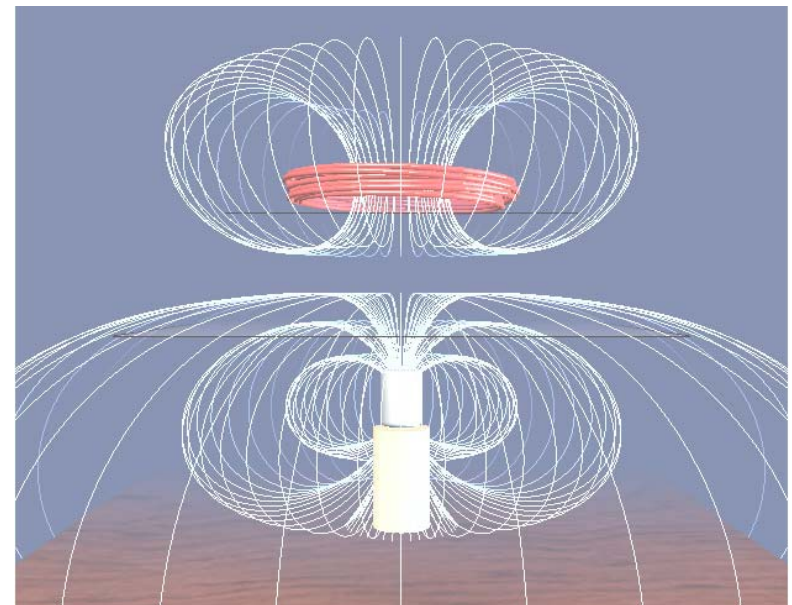
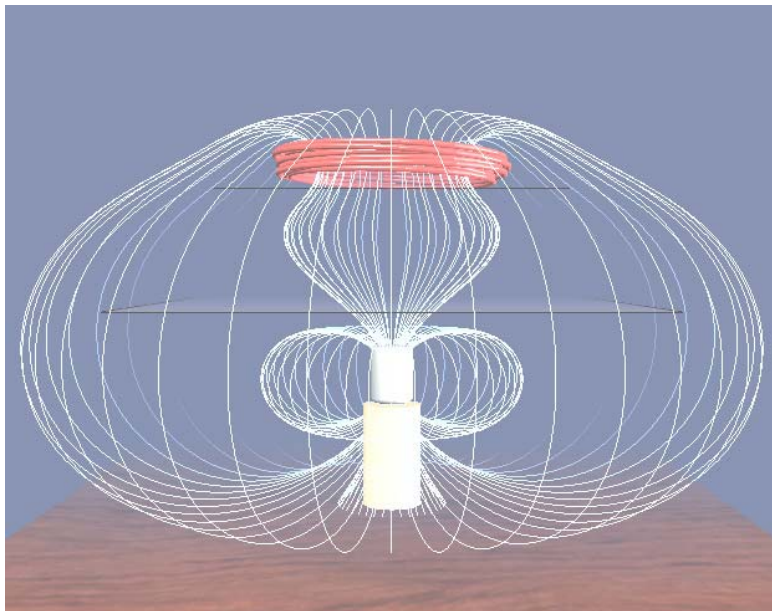
- In large lectures, polling is usually done with a Personal Response System (“clickers”). These are low-cost (~\$10-30 new on amazon.com) and can send responses directly to a laptop via a USB-connected radio receiver, allowing for rapid display of results.
- Note that interaction in lectures does not require a demonstration; conceptual PRS questions also stimulate peer discussion.

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.

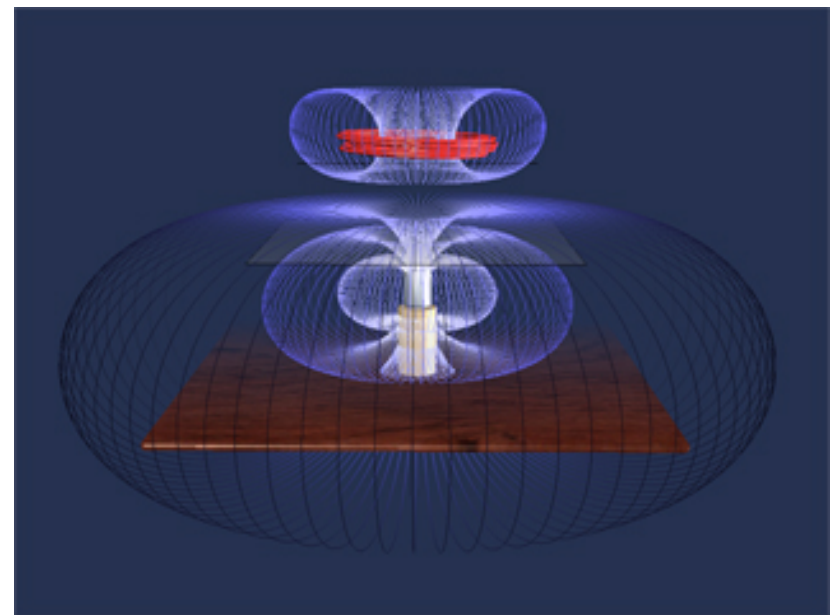
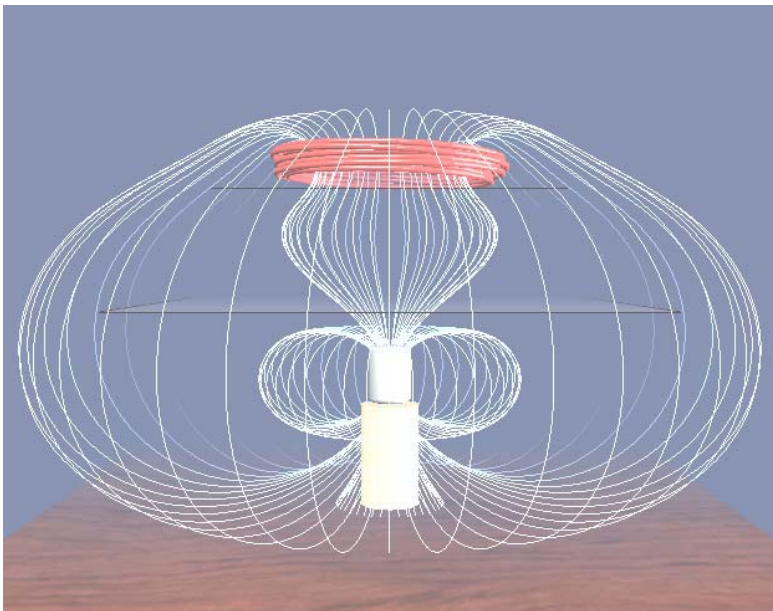
(with permission from J. Belcher, MIT)



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.



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
 - May take more time to cover the same topic.
 - Technical operation represents an initial barrier.
- Who uses them: Tufts, U. Oregon, U. Illinois, U. Maryland, MIT, Harvard, Stanford ☺

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.

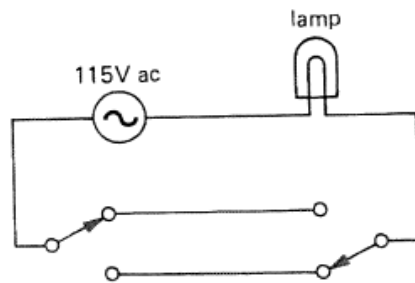


Figure 1.101. Electrician's "three-way" switch wiring.

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.)

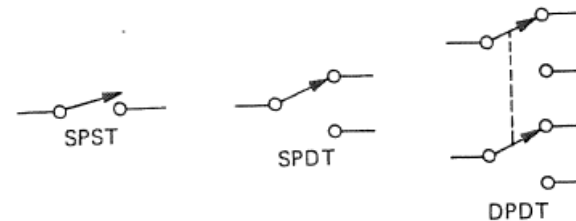


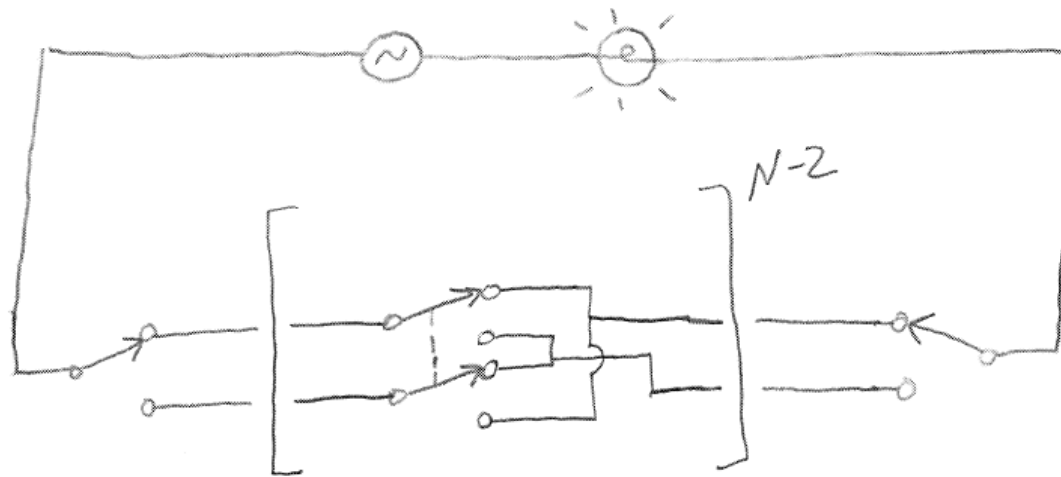
Figure 1.98. Fundamental switch types.

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.

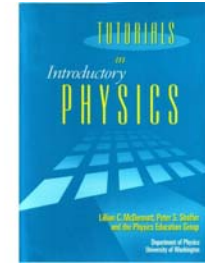


TUTORIALS

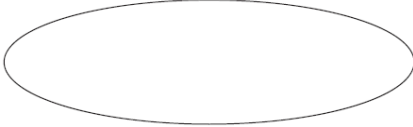
- Traditional discussion section: teaching assistant (usually a graduate student) works through problems on the board, pausing occasionally to answer questions or to give students a chance to try a problem on their own
- Tutorial recitation:
 - Students work on problems in teams
 - Teaching assistants give guidance, not lectures
 - 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).
 - In a team of more than 3, someone is always separated from the writing board by one person.
 - 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.
 - Group work probably requires a reconfiguration of the seats/tables in the classroom from a normal discussion setup.

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?

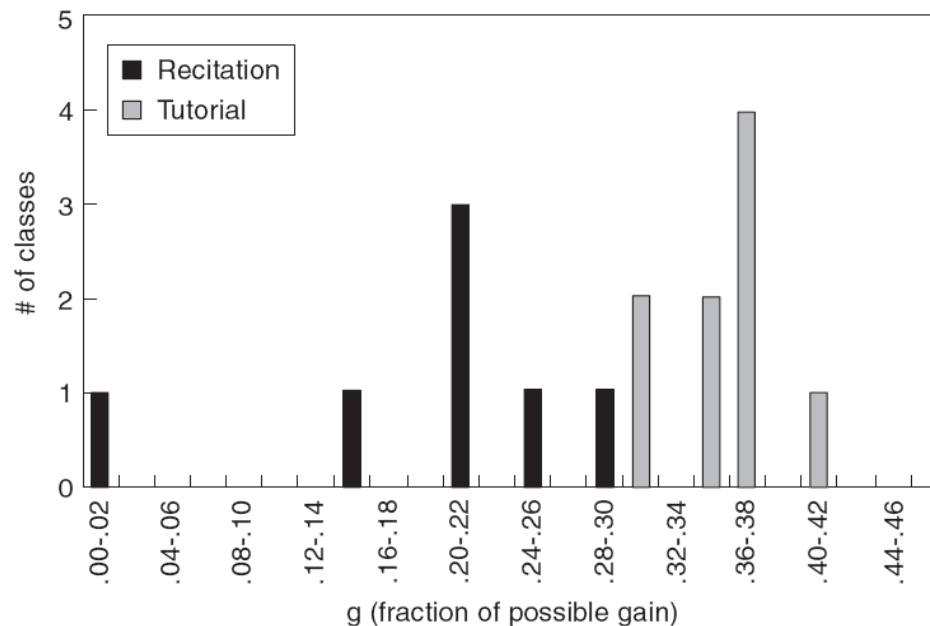
ii. How would you find the acceleration at point C?

- 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

- 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



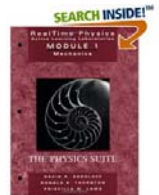
Source: TPPS p. 151

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

- Data acquisition in action (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>)
- Useful for teaching the “hidden curriculum” of physics
 - Understand uncertainty in experimental data
 - Learn how to model the relationship between two variables (independent, directly proportional, inversely proportional, etc.)
- Black box nature of sensors requires “psychological calibration” to understand how they work

REAL TIME DATA ACQUISITION LABS

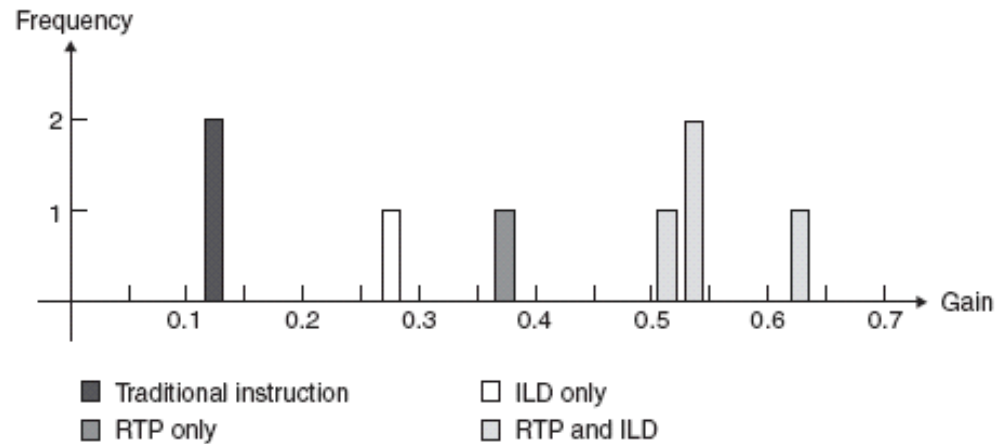


Figure 8.13 Fractional gains on the FMCE in five different colleges and universities that used fully traditional instruction, or traditional lectures with RTP, or RTP and ILDs ($N = 1000$) [Wittmann 2001].

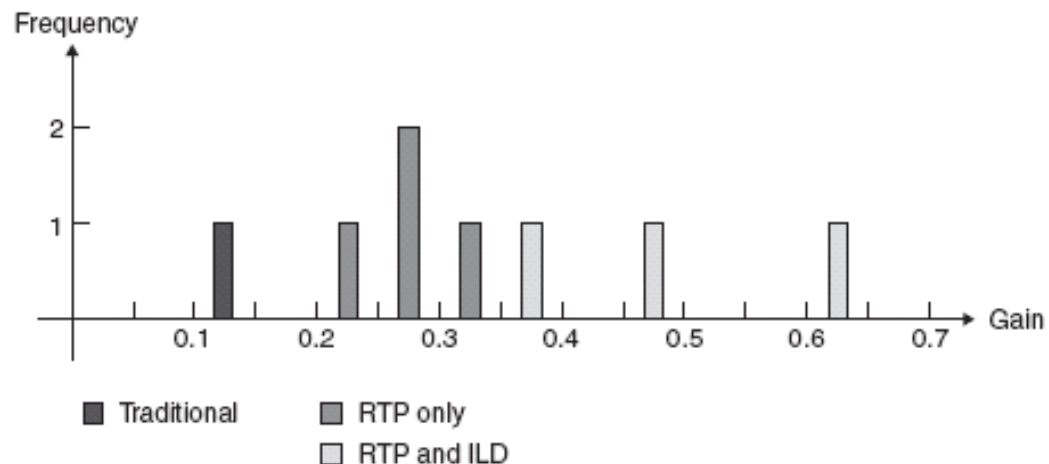


Figure 8.14 Fractional gains on the ECCE at four different colleges and universities that used fully traditional instruction, or traditional lectures with RTP, or RTP and ILDs ($N = 797$) [Wittmann 2001].

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

Source: TPPS p. 168-169

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

Inertia is powerful, but even big institutions can change.

**No one has a monopoly on excellent teaching practices,
so stay on the lookout for more good ideas!**



MATERIALS

- Easel paper
- Markers
- Tutorial question papers
- Spool/thread
- Quicktime videos