Effective reforms in undergraduate physics education

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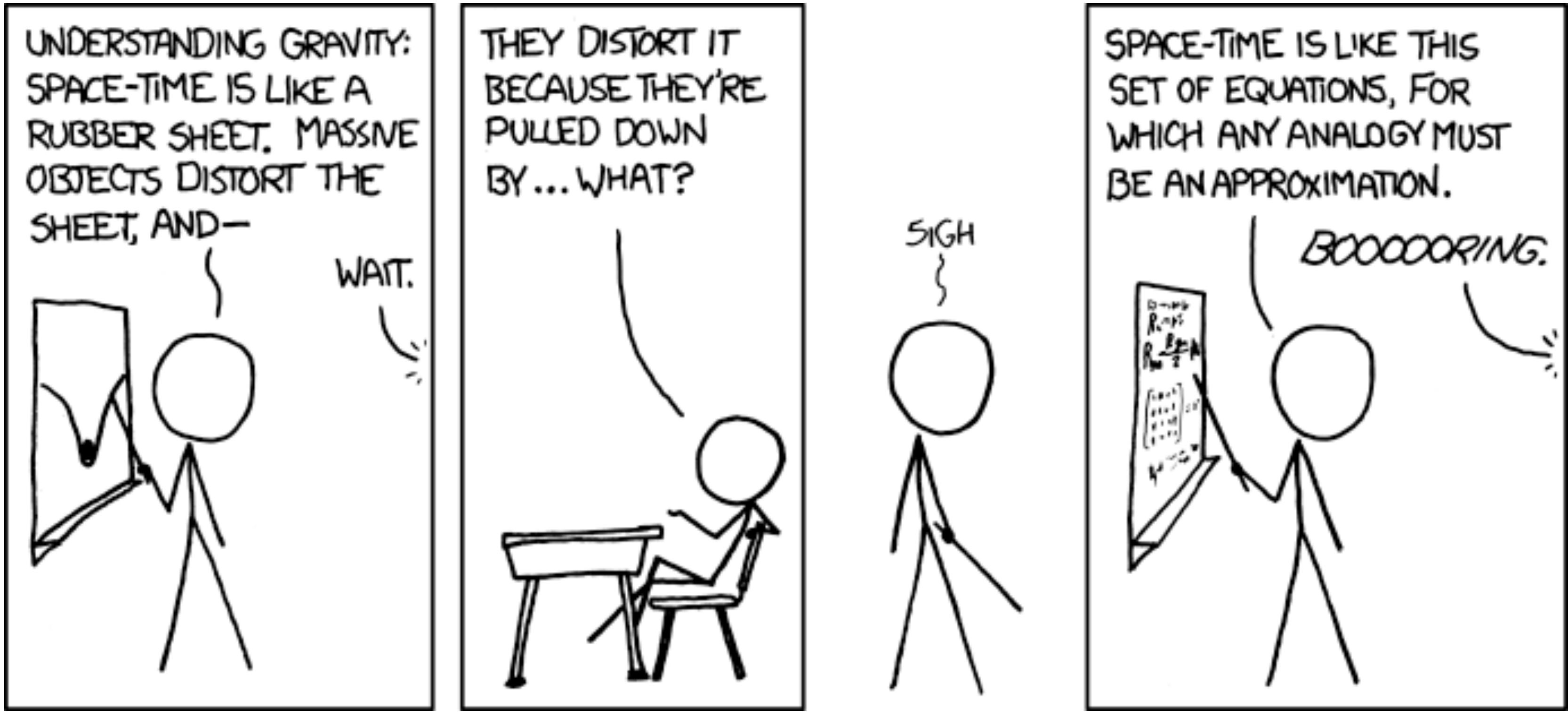


Relevant xkcd is relevant

Outline

- Inherent challenges in science education
- Measuring & quantifying conceptual knowledge
  - Measuring the effectiveness of an instructional strategy
- What teaching methods are effective?
- How to better implement reforms

Challenges in teaching science

- Think back to your college days – were there any differences between a physics class and a typical gen. ed. class?
  - How you were taught
  - How you studied
- Before taking a class on it, it's doubtful you have many preconceived notions about 18th century French art or Keynesian economics
  - What about forces and motion?

Challenges in teaching science

- Important difference between learning science vs. many non-science subjects
  - Science (physics in particular) addresses things we’re already quite familiar with
    - Eg. Heat, motion, electricity, etc.

- Unfortunately, people’s preconceptions are generally incompatible with the modern scientific view of the universe

Challenges in teaching science

- You can train factual recall without having any meaningful understanding of a subject

- Easy to fool yourself into thinking you understand things when a course stresses facts over understanding
  - Self-reported knowledge an untrustworthy measure of learning

Challenges in teaching science

- Main points
  - All people have preconceptions about how the world works. As a science teacher, you ignore them at your own peril.
  - Traditional classes can compound the issue by stressing facts / textbook problems over deep conceptual understanding.

Education as calculus of variations

- Broadly, education consists of three components
  - Identifying what we want students to know
    - the final state
  - Identifying students' current knowledge state
    - the initial state
  - Finding the most efficient way to get from the initial to final state
    - the brachistochrone of knowledge!

What we want students to learn

- What should students get out of an intro physics course?
- What about an advanced undergraduate physics course?

Measuring students' preconceptions

- Many tools developed by physicists and educators together
  - We love to quantify things!
- We'd like to measure conceptual understanding as best we can, separate from mathematical ability
  - This is the origin of the Force Concept Inventory (FCI; Halloun & Hestenes, 1985; Hestenes et al., 1992)

Measuring students' preconceptions

- The FCI is a multiple choice test developed from free-response questions and interviews with 1000s of students over ~3 years
  - Designed to force students to choose between Newtonian and pre-Newtonian ways of thinking
  - 30 questions with answers targeting 28 identified misconceptions

Measuring students' preconceptions

- Examples of common pre-Newtonian conceptions of force & motion
  - Associating force with velocity rather than acceleration
  - Using the 'dominance principle' over Newton's 3rd Law
  - Thinking that objects in circular motion tend to stay in circular motion

Measuring students' preconceptions

- How well does the FCI perform?
  - Validity – does the test measure what it intends to measure?
    - Yes – checked via interviews
  - Reliability – the stability of the test (eg. to measure the same score from the same student at different times)
    - Kuder-Richardson test: 0.86-0.89 (very high)

Measuring students' preconceptions

- Think of the FCI as defining a minimum standard for Newtonian thinking
  - Typical threshold is set at 85% (Hestenes et al., 1992)
- Lower scores indicate that a student is in danger of reinforcing misconceptions and systematically misinterpreting future instruction

FCI results in high schools

Table IV Arizona Inventory Scores vs Teacher Competence Ranking

Teacher Competency Ranking	Regular Pre %	Regular Post %	Honors Pre %	Honors Post %	AP Pre %	AP Post %	Socio-Econ. Level of School	Number of Students
1	28	48					4	50
2	24	45	30	52	56	64	5	7/26/8
3	29	53					3	35
4	25	44					1	93
5	34	59					3	18
6			39	67			2	46
7	25	52					3	67
8	29	46					3	73
9	28	40	25	40	39	47	4	32/36/9
10					35	60	2	16
11	30	51					2	42
12	28	64					5	15
13	25	49					3	12
14			37	73			2	10
15	27	50					2	75
16	31	47					1	45
17	24	44					1	12
18	23	33					5	26

Remarks: Teacher competency ranking #1 corresponds to the most competent teacher. Socioeconomic level #1 corresponds to the school with the highest socioeconomic student populations.

(Halloun & Hestenes, 1985)

Quantifying knowledge gains

- First, need an agreed upon instrument for evaluating knowledge (eg. a concept inventory like the FCI)
- Common metric of improvement is the normalized gain (between 0 and 1):

$$g = \frac{\%S_f - \%S_i}{100 - \%S_i}$$

$\%S_i$ – initial score
$\%S_f$ – final score

What g (on the FCI) doesn't tell us

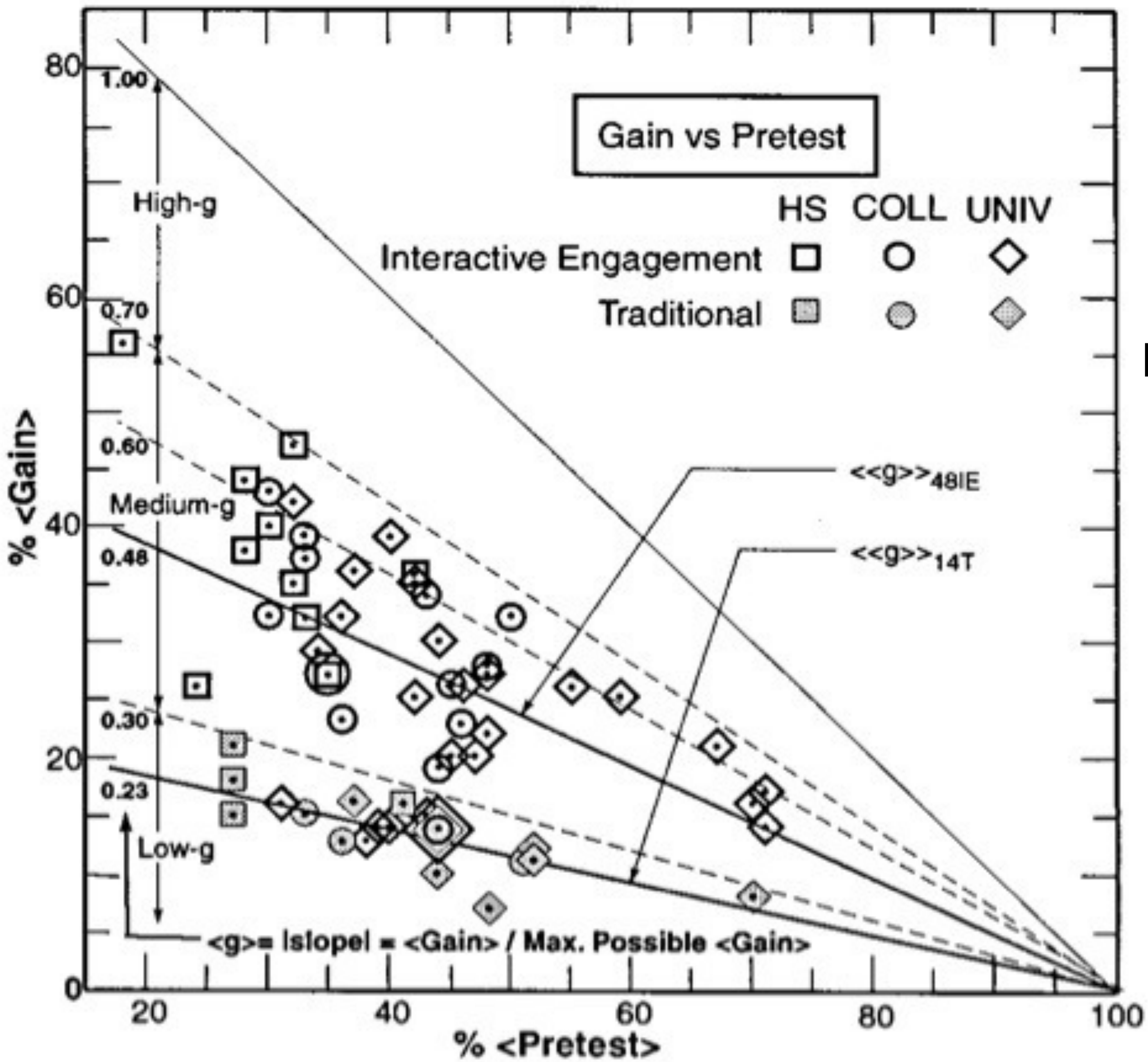
- Interest & satisfaction with physics
- Understanding of scientific methodology
  - Range of validity of certain theories
- Interpersonal & communication skills
- Ability to solve real-world problems
  - Estimation/approximation skill
  - Identification of what processes are at work
  - Error analysis

Ineffectiveness of traditional physics classes

- Students' preconceptions are generally incompatible with Newtonian views (McDermott, 1991)

- Traditional physics classes do little to remedy this (Houllon & Hestenes, 1985)
  - 80% of students can correctly state Newton's 3rd Law at the beginning of a course, while <15% 'understood' it by the end (Hestenes, 1998)
  - Typical normalized gains: g~0.25

Can we do better?



N ~ 6000 students

Hake (1998)

Effective instructional methods

- Some examples, roughly in order of difficulty to implement
  - Peer instruction
  - Interactive demonstrations
  - Guided inquiry
  - Modeling & project-based instruction

- All have one important thing in common – interactivity!

The intro physics class

- 300,000 students/yr take intro physics labs in college (Sokoloff et al., 2007)
- Only 1 in 33 students in a calc-based intro physics class will go on to major in physics
  - Roughly 1/3 of physics majors get a graduate degree in physics (Rigden, 1997)

- Yet these courses are still tailored towards future physicists
  - Eg. development of mathematical rigor before concepts are adequately internalized

Peer instruction

- Teaching method developed by Harvard physics professor Eric Mazur in 1991 (Mazur, 1997)
- Designed for large-lecture format classes
- Effort required of instructor is relatively low
- Lectures broken into small 5-15 min chunks
  - Conceptual questions (ConcepTests) interspersed highlighting the point just presented

Peer instruction

- Students think on their own and vote on an answer (eg. with cards or iClickers)
- Typically there's a spread in answers, so they discuss it with their peers

Peer instruction

- Students then re-vote to see if opinions have shifted
- Finally, there’s a class-wide discussion where students defend their choices

Example question I used (Phys 2)

- A satellite is moving around the Earth in a circular orbit. Over the course of an orbit, the Earth's gravitational force

A. does positive work on the satellite.

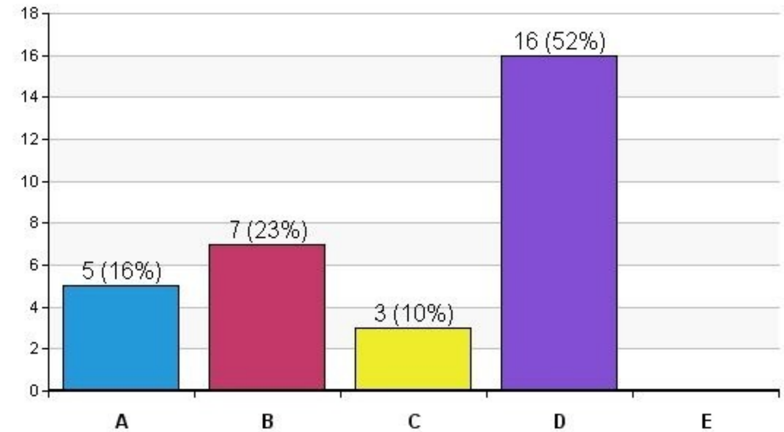
B. does negative work on the satellite.

C. does positive work on the satellite during part of the orbit and negative work on the satellite during the other part.

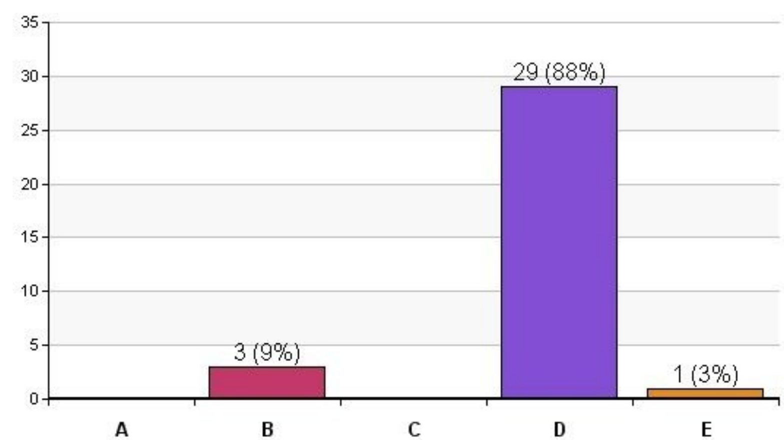
D. does zero work on the satellite at all points in the orbit.

Example question I used (Phys 2)

- Before discussion



- After discussion



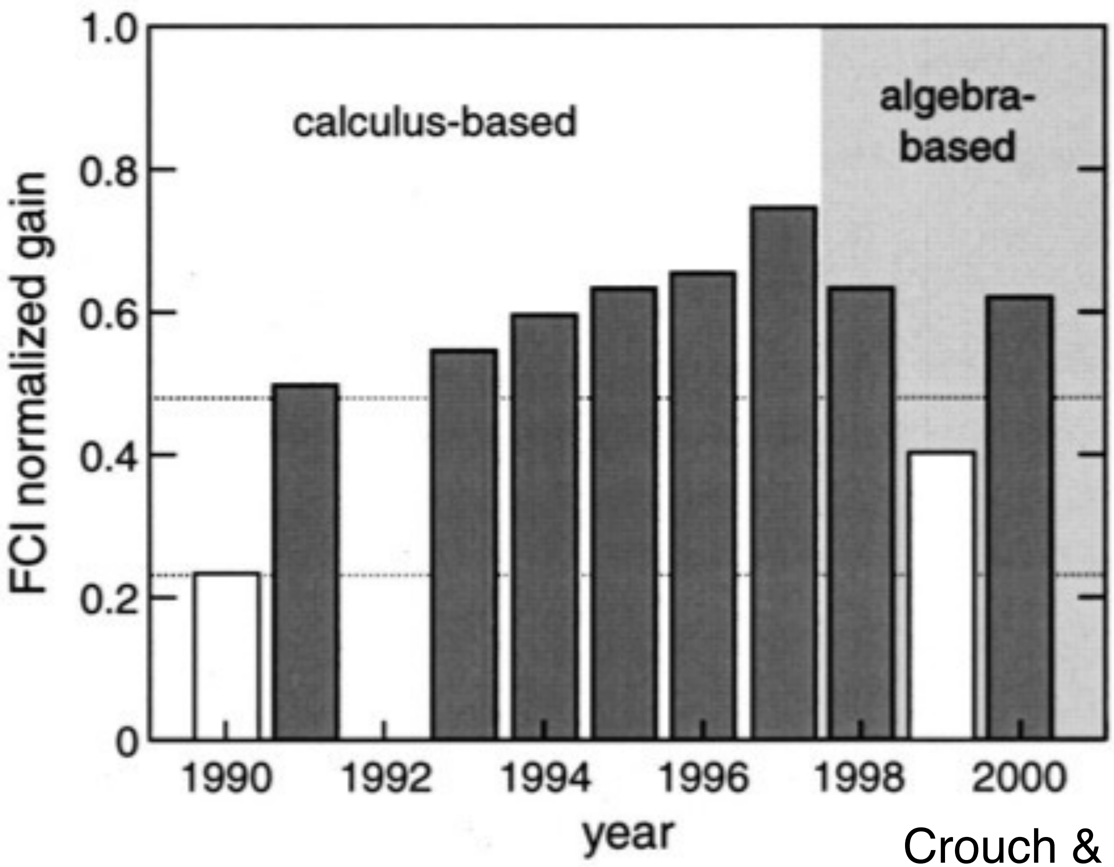
Peer instruction

- Typically each ConcepTest takes ~5-10 minutes
  - Should have 2-3 in a 50 min. class
  - Important to discuss why incorrect answers are incorrect (Turpen & Finkelstein, 2009)
- This means there's less time for lecturing!
  - Don't lecture out of the book at all
  - Have students do the reading beforehand
  - It's okay to cover less material in lectures

Peer instruction

- Does it work?

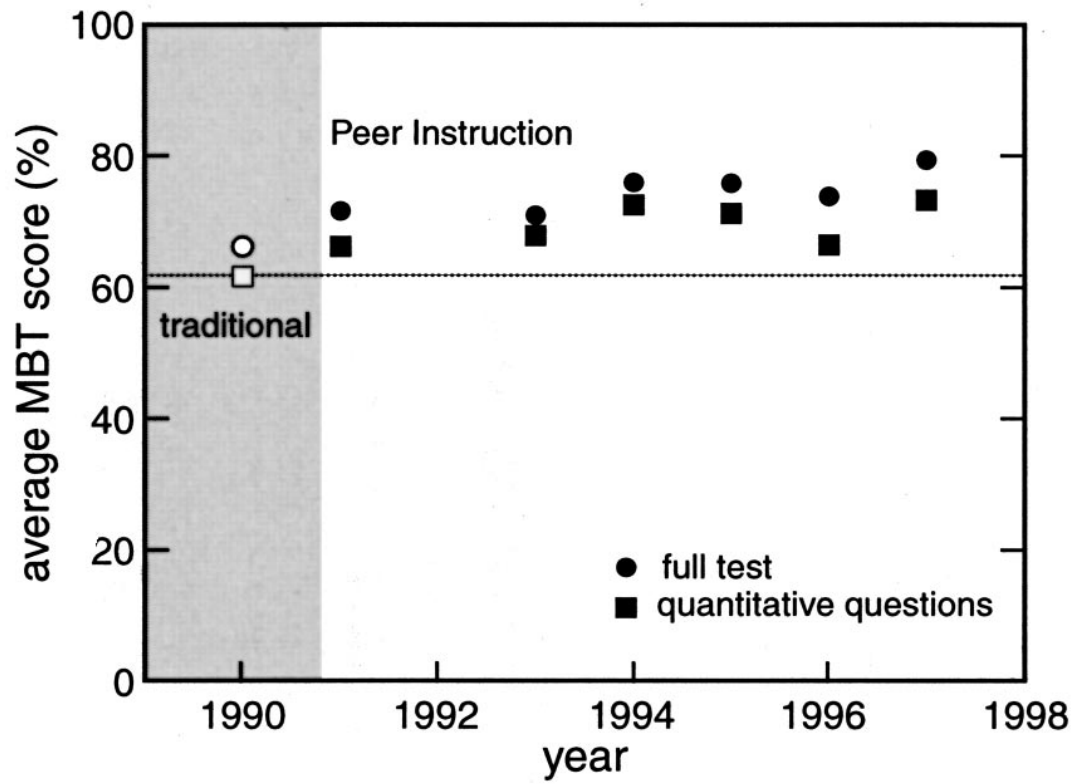
Unshaded: traditional courses
Shaded: peer instruction



Crouch & Mazur (2001)

Peer instruction

- Do quantitative problem solving skills suffer?



Crouch & Mazur (2001)

Peer instruction

- Other advantages:
  - Instant feedback on whether students understood what you just presented
    - Better to review right away then to forge ahead without a proper foundation
  - Students get comfortable asking questions more quickly
  - Lectures are much more fun!
    - You spend them discussing physics rather than going through derivations/examples

Motivating students

- *Students praise teachers who give clear lectures, who reduce confusion. Student evaluations of teaching reward that clarity. Students prefer not to be confused.*

  -Eric Mazur

- However, confusion at some level is a requirement for conceptual change

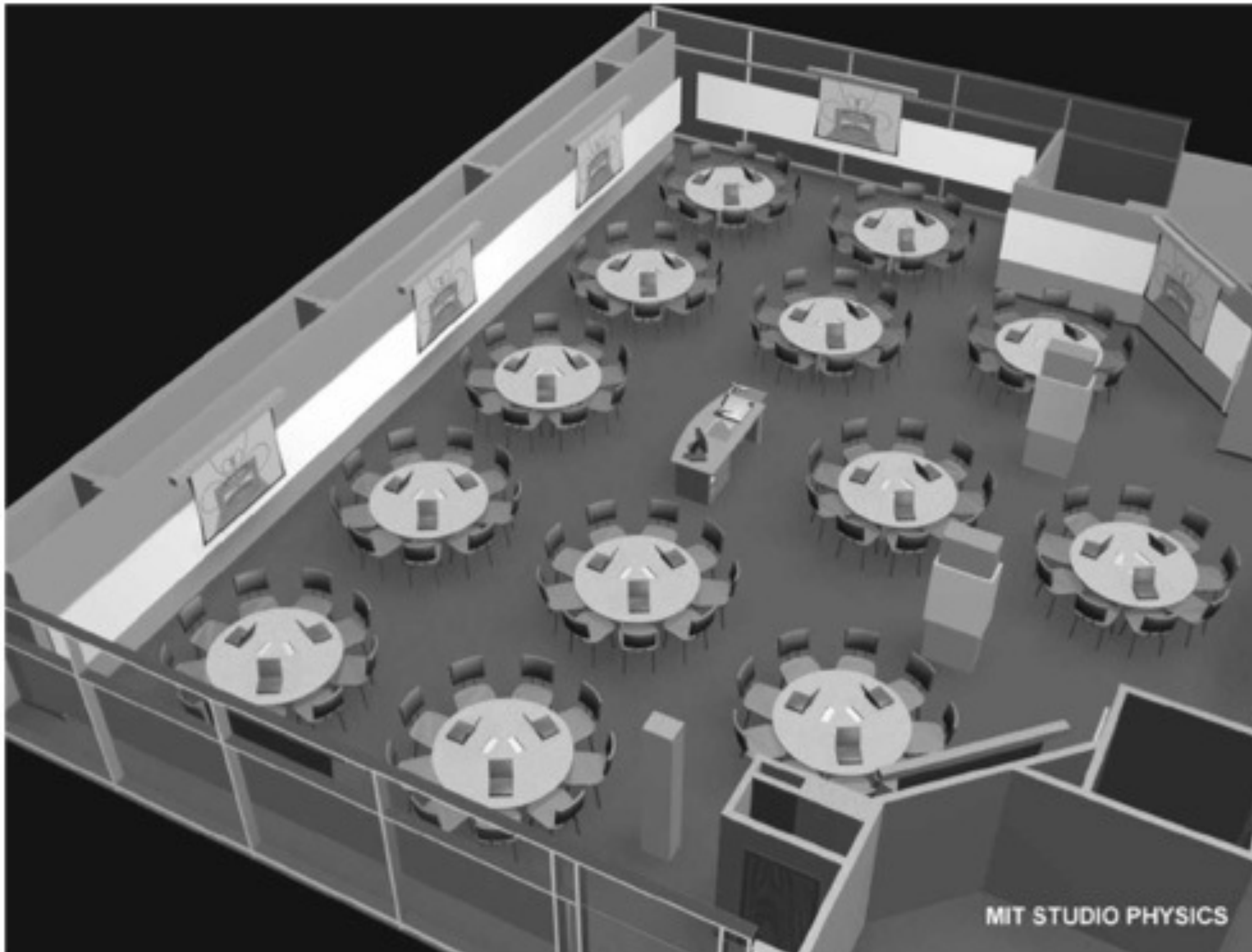
Motivating students

- Explain that reading the book at them is a waste of everyone's time
- Show research on how students learn much more when they're actively engaged
- Use interesting demos* whenever possible
- If you want to stress concepts in your course, you must have them appear in your homework assignments & tests
- Get frequent feedback from students

TEAL

- Technology-Enabled Active Learning
- Developed at MIT in 2000 and targets large-enrollment E&M course (Dori et al., 2007)
- Main goals:
  - Decrease the failure rate in the intro physics classes
  - Move away from passive lecture/recitation format
  - Increase students' conceptual knowledge and visualization skills

TEAL



TEAL

TABLE 2
Relative Improvement of Conceptual Understanding of Fall 2001 and Spring 2003 Experimental Groups Versus the Spring 2002 Control Group Students

	Experimental Fall 2001		*Experimental Spring 2003*		*Control Spring 2002*	
Group	*n*	$\langle g \rangle$	*n*	$\langle g \rangle$	*n*	$\langle g \rangle$
Total ($N = 811$)	176	0.46	514	0.52	121	0.27
High	58	0.56	40	0.46	19	0.13
Intermediate	48	0.39	176	0.55	50	0.26
Low	70	0.43	298	0.51	52	0.33

(Dori et al., 2005; 2007)

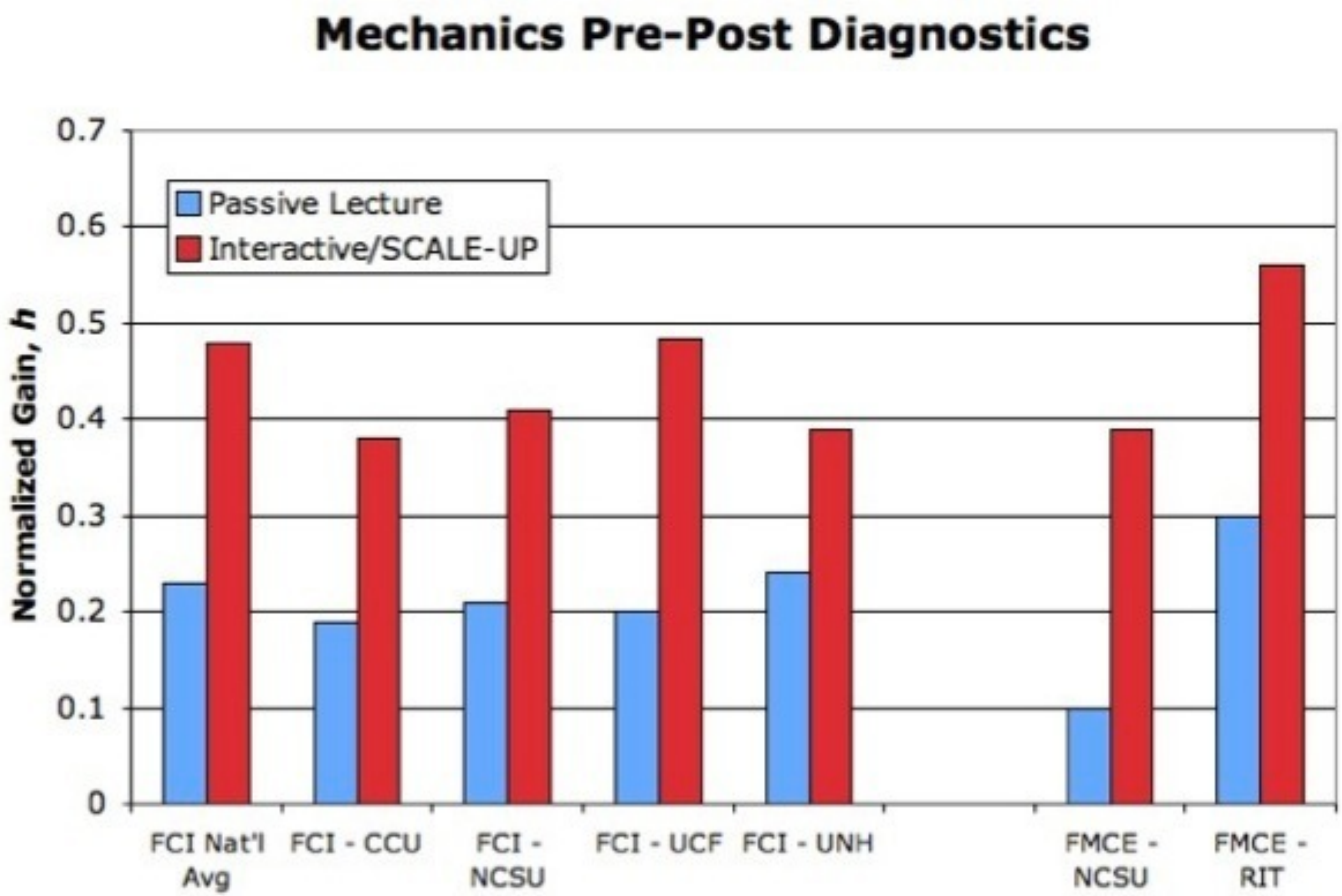
SCALE-UP

- Student-Centered Activities for Large Enrollment Undergraduate Programs (Beichner, 2002)

- Started at NCSU around 1997
  - Very similar to TEAL (and a significant influence on it)
  - Now used at over 50 colleges

SCALE-UP

SCALE-UP

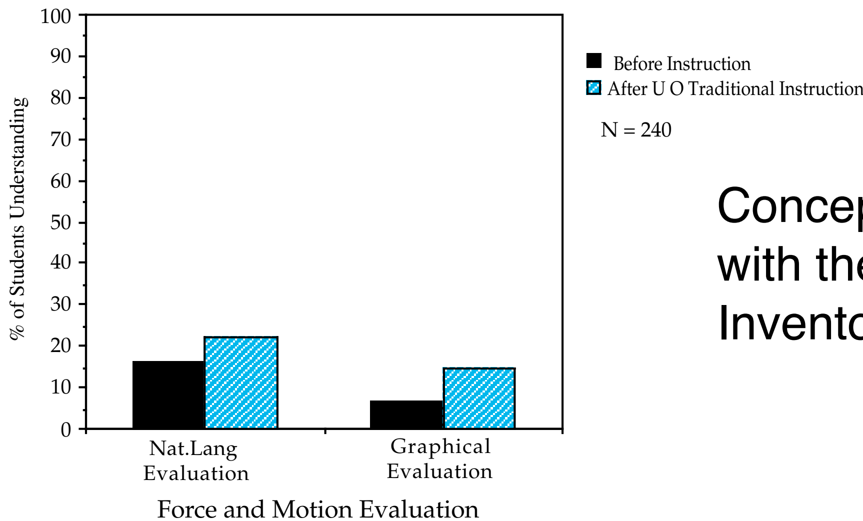


(Beichner, 2002)

RealTime Physics

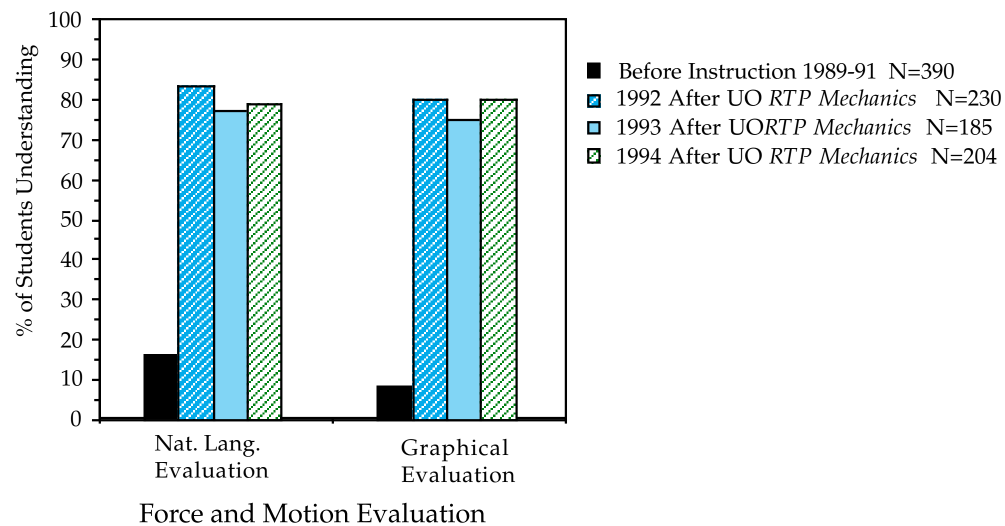
- Set of interactive computer-aided mechanics labs and related homework assignments
  - Goals similar to TEAL, SCALE-UP, etc.
  - Also used in over 50 colleges (>15,000 students/yr)

RealTime Physics



Conceptual knowledge evaluated with the Force and Motion Conceptual Inventory (FMCI)

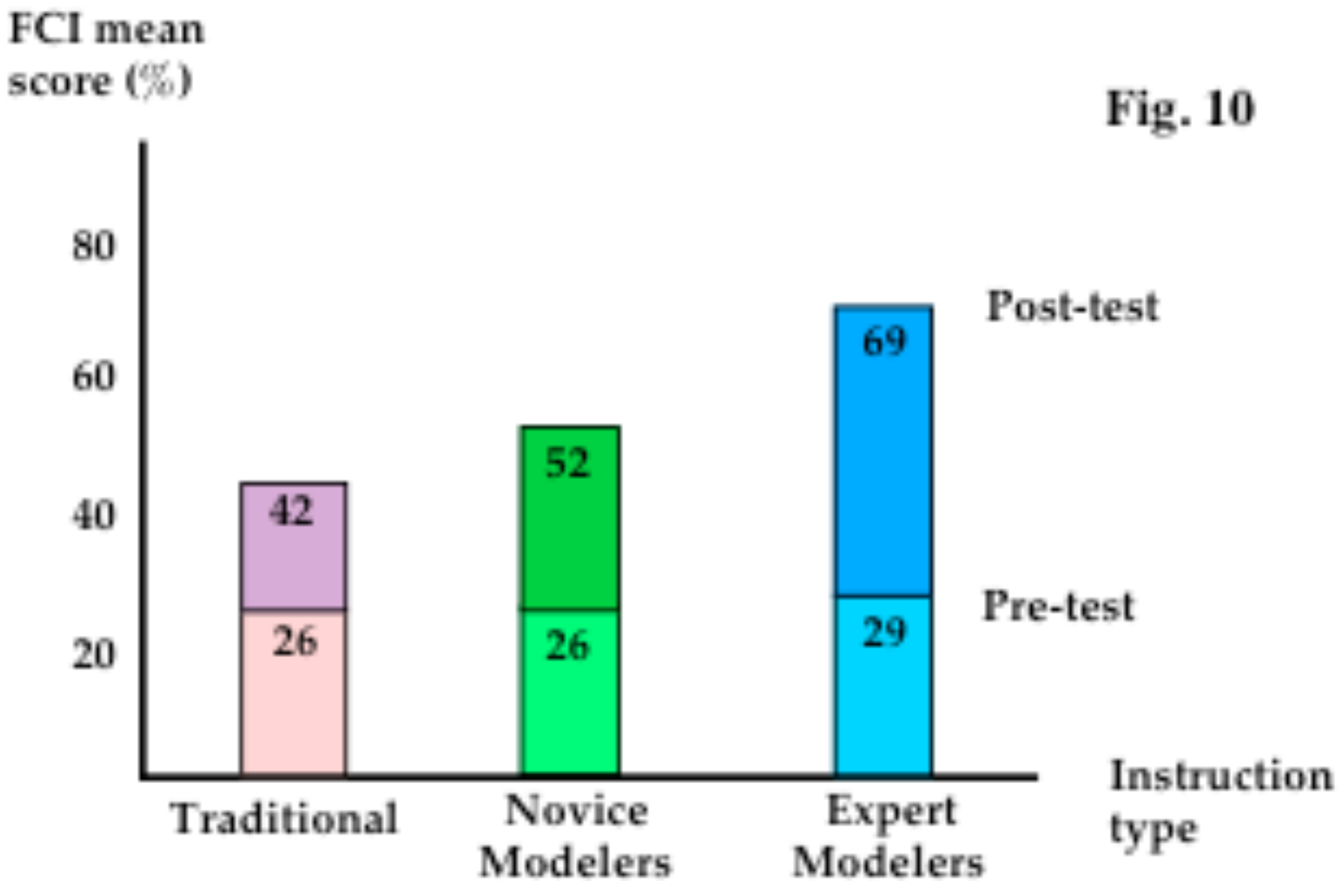
Sokoloff et al., 2007



Modeling-based instruction

- Basically a teaching method that involves students being guided to discover physical laws themselves
- Teaches the process of science much more authentically than other methods
- Very high teacher commitment
  - Not much reusable material from traditional courses
  - High student gains require experience

Modeling-based instruction



FCI mean scores under different instruction types

(Hestenes, 2006)

Why are interactive strategies more effective?

- Main educational theories that inform physics education research (PER) are:
  - Social constructivism – information is not transmitted (eg. through a lecture), students need to create their own knowledge (Driver et al., 1994)
  - Conceptual change theory – internal preconceptions need to be addressed (Strike & Posner, 1992)

Challenges in implementing new education strategies

- Teacher education often needed
  - less so at the undergraduate level since instructors have at least a masters degree in physics
- Inadequate student preparation from high school and/or previous courses
- Students expect classes to be a certain way and require motivation to embrace ‘alternative’ classes

Where to go from here

- Blogs
  - ScienceGeekGirl
    http://blog.sciencegeekgirl.com/
  - Turn to Your Neighbor
    http://blog.peerinstruction.net/
  - Action-Reaction
    http://fnoschese.wordpress.com/
  - ThinkThankThunk
    http://shawncornally.com/wordpress/

Where to go from here

- Websites
  - PhET

    http://phet.colorado.edu/
  - NASA Center for Astronomy Education

    http://astronomy101.jpl.nasa.gov/
  - PER User's Guide

    http://perusersguide.org/
  - Physics Education Research Central

    http://www.compadre.org/per/

Where to go from here

- Journals
  - APS Supplement - Physics Education Research

    http://prst-per.aps.org/
  - The Physics Teacher

    http://tpt.aapt.org/
  - American Journal of Physics

    http://ajp.aapt.org/

The End!

Teach me and I’ll forget;
show me and I may remember;
involve me and I’ll understand
-Chinese proverb