Educating Scientifically

Advances in Physics Education Research: Studies of Transforming Undergraduate Physics

Fermi National Accelerator Laboratory
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Outline / Framing

- Brief overview of why, what, and how of PER
  - State of education
  - Why physicists?
  - Theoretical models & Educational practices
- Applying what we know
  - Implementing course transformation
  - Studying the process
- A sample of other CU research in PER
- New Directions

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

What's our goal?

"By the Year 2000, United States students will be first in the world in mathematics and science achievement"

Goals 2000: Educate America Act

Pub. Law 103-227 (108 Stat. 125) 4/26/96

- originally from the 1989 National Gov's Conference.

How are we doing: TIMSS

Average Physics Performance of Advanced Science Students in All Countries

NATIONS WITH AVERAGE SCORES SIGNIFICANTLY HIGHER THAN THE U.S.	
NATION	AVERAGE
NORWAY	581
SWEDEN	573
(RUSSIAN FEDERATION)	545
(DENMARK)	534
(SLOVENIA)	523
(GERMANY)	522
(AUSTRALIA)	518
(CYPRUS)	494
(LATVIA)	488
SWITZERLAND	488
GREECE	486
(CANADA)	485
FRANCE	466
CZECH REPUBLIC	451

NATIONS WITH AVERAGE SCORES NOT SIGNIFICANTLY DIFFERENT FROM THE U.S.	
NATION	AVERAGE
(AUSTRIA)	435
(UNITED STATES)	**423**

NATIONS WITH AVERAGE SCORES SIGNIFICANTLY LOWER THAN THE U.S.	
NATION	AVERAGE
NONE	

INTERNATIONAL AVERAGE = 501

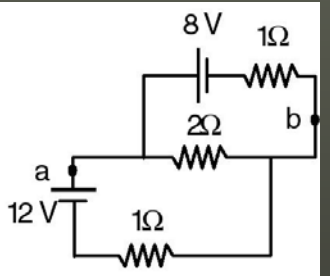
http://timss.bc.edu

How are we doing: Harvard

- (University) Students fail to learn basic concepts in (introductory physics) classes.

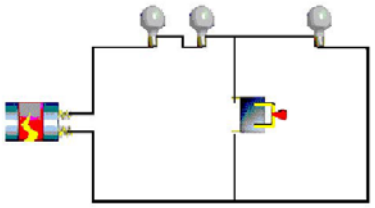
E.g.

1. Find the current through the 2 ohm resistor and the potential difference between points a and b.



~75%

2. In the circuit to shown, explain what will happen to the following variables when the switch is closed:
   - the current through the battery
   - the brightness of the bulbs
   - the voltage drop across the bulbs
   - the total power dissipated



~40%

From: Mazur (1997)

Rising Above Gathering Storm

Congressional charge (2005):

What

to e

con

?

4

#1:

#2

#3

#4: INCENTIVES FOR INNOVATION

APRIL 24 2007:

House of Representatives
passes H.R. 362,
10,000 Teachers, 10 Million Minds Science and Math Scholarship Act.

APRIL 26 2007:

Senate Passes S. 761,
The America COMPETES Act
America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act

" and a
decompressor
his picture.

Overview of PER

- Far more to our classes than what has been traditionally evaluated
  - Our students are not learning what we believe them to
  - They are learning some things we would not expect
- Sub-field of physics education research has something to say about this
  - Tools for assessment
  - Models of student learning
  - Suggestions for curricula / approaches in class

What are our goals in class?

Novice		Expert
Formulas & "plug 'n chug"	content	Concepts & Problem Solving
Pieces	structure	Coherence
By Authority	process	Independent (experiment)
Drudgery	affect	Joy

think about science like a scientist
think about education like a scientist

Adapted from: Hammer (1997) COGNITION AND INSTRUCTION (physics),

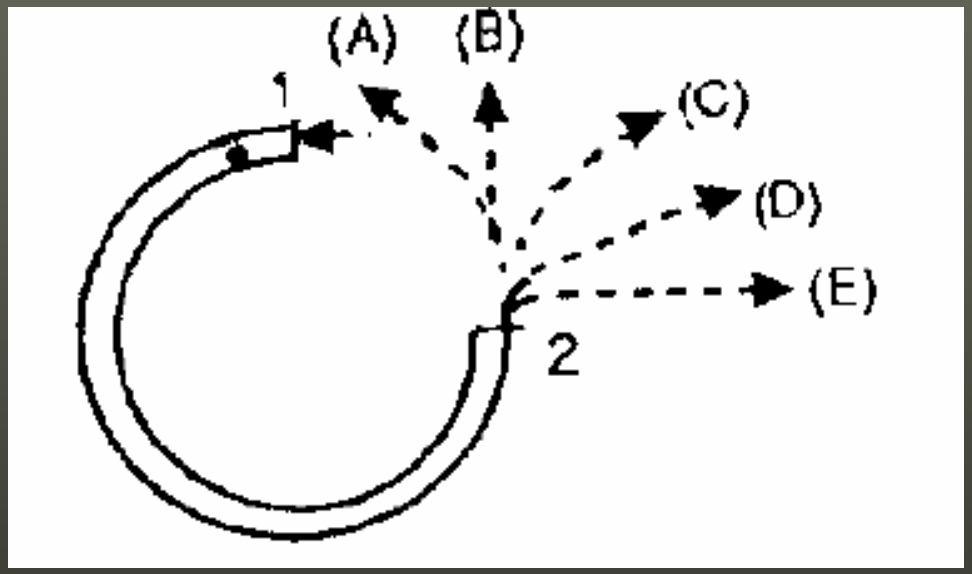
A possible “tipping” point

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

  necessary (not sufficient) indicator of conceptual understanding.

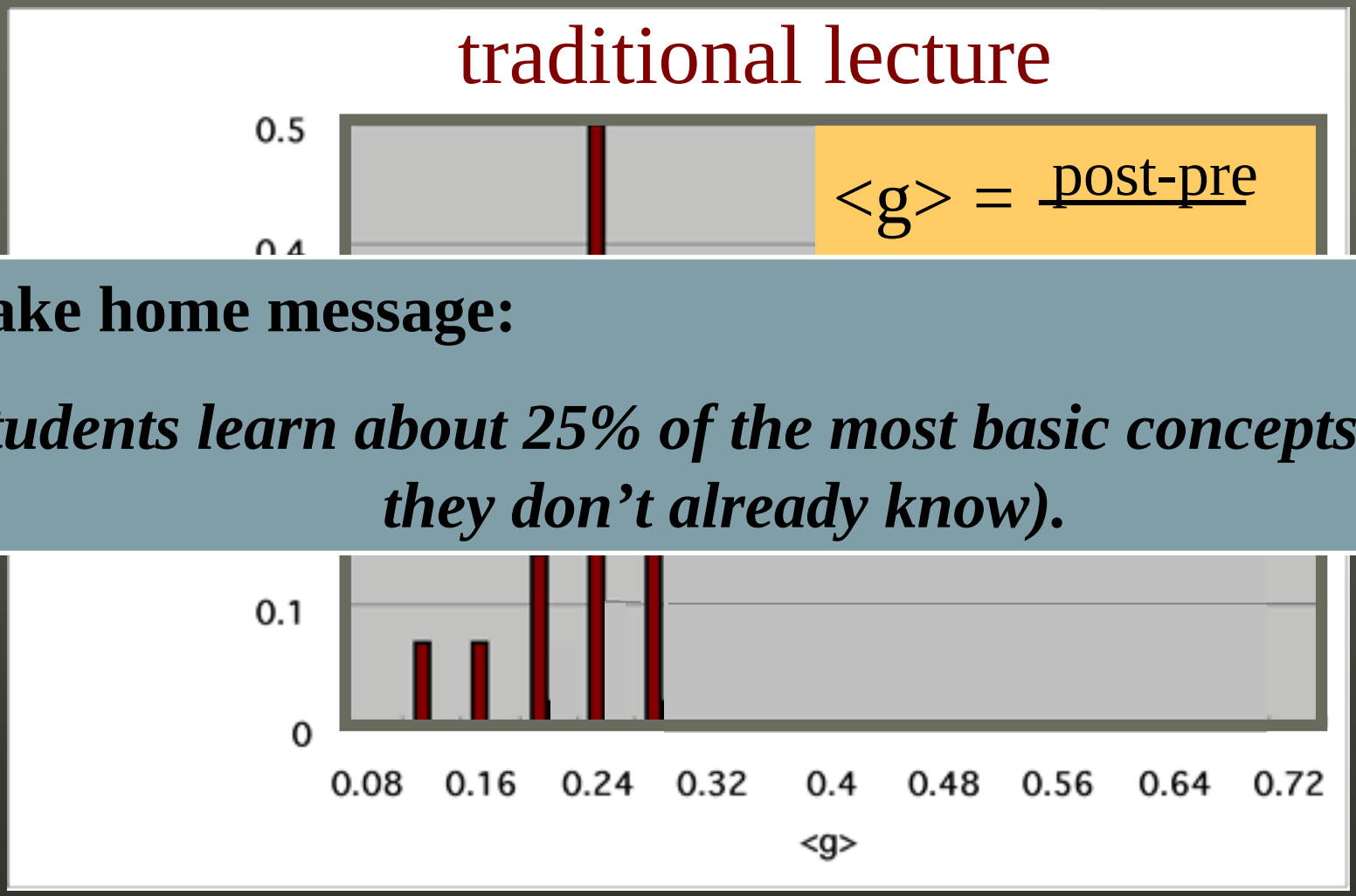
* Hestenes, Wells, Swackhamer, Physics Teacher 20, (92) 141

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



$$\langle g \rangle = \frac{\text{post-pre}}{}$$

Take home message:

Students learn about 25% of the most basic concepts (that they don't already know).

R. Hake, "…A six-thousand-student survey…" AJP **66**, 64-74 ('98).

Attitudes & Beliefs:

Attitudes and Beliefs*

Assessing the "hidden curriculum" - beliefs about physics and learning physics

Examples:

- "I study physics to learn knowledge that will be useful in life."
- "To learn physics, I only need to memorize solutions to sample problems."

*Adams et al, (2006) Physical Review: Spec. Topics: PER, 0201010

CLASS categories

	Shift (%) ("reformed" class)	
Real world connect...	-6	
Personal interest.....	-8	Engineers: -12
Sense making/effort...	-12	
Conceptual.....	-11	
Math understanding...	-10	
Problem Solving.....	-7	
Confidence.....	-17	Phys Male: +1 Phys Female: -16
Nature of science.....	+5	

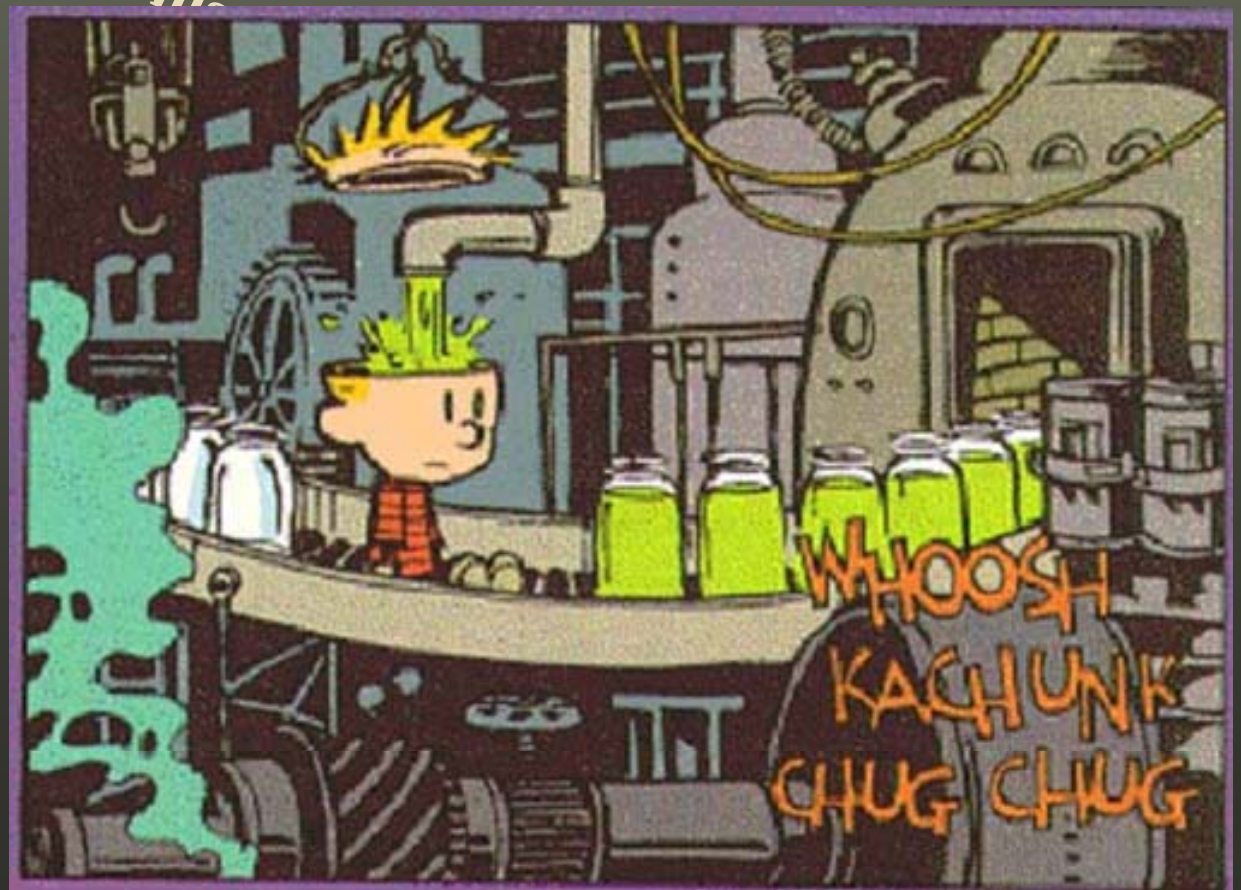
(All ±2%)

why does this happen?

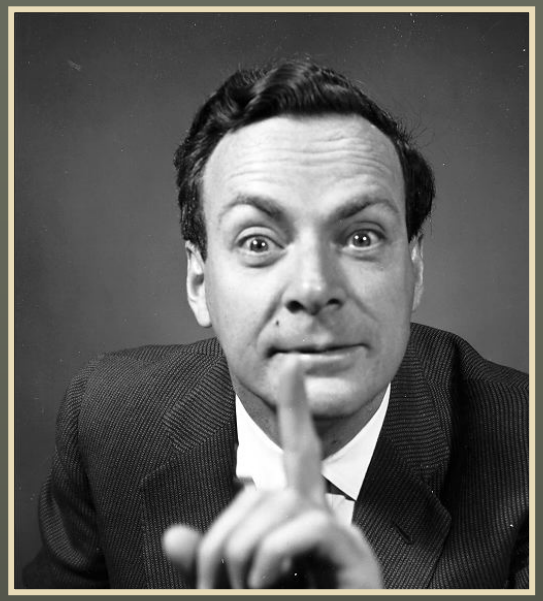
Trad'l Model of Education

Individual ← Instruction via transmission — Content (e.g. circuits)

transmissionis



Built in to our classes?



Feynman

I don't think you can teach physics very well anyway to people in that manner, by giving lectures on a big scale. I think it's hopeless.

Richard Feynman, 1918-1988

PER Theoretic Background

Individual ← Instruction via transmission — Content (E/M)

transmissionist

Individual ↔ Active construction — Content

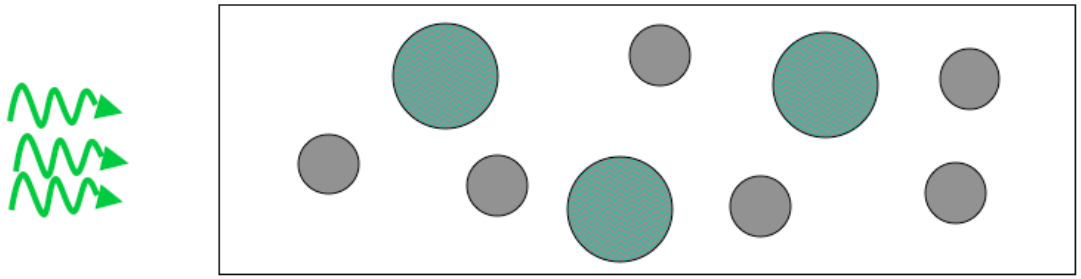
Prior knowledge

constructivist

actively engaging students is important

Personal Response System

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



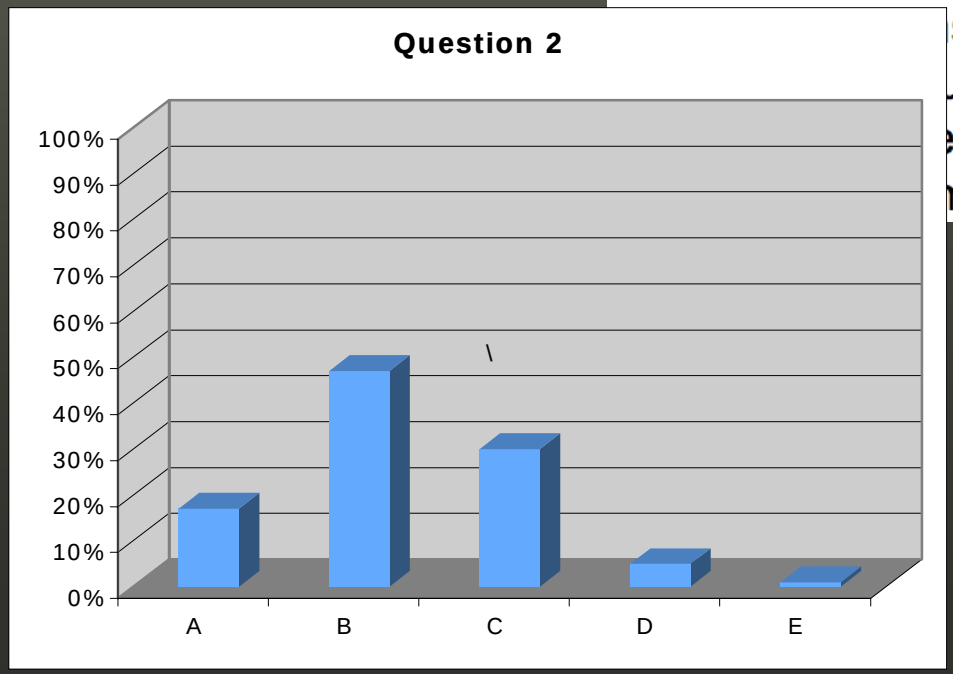
Expect that on average

s will come out right hand end of tube

ut right

er as go in

me out.



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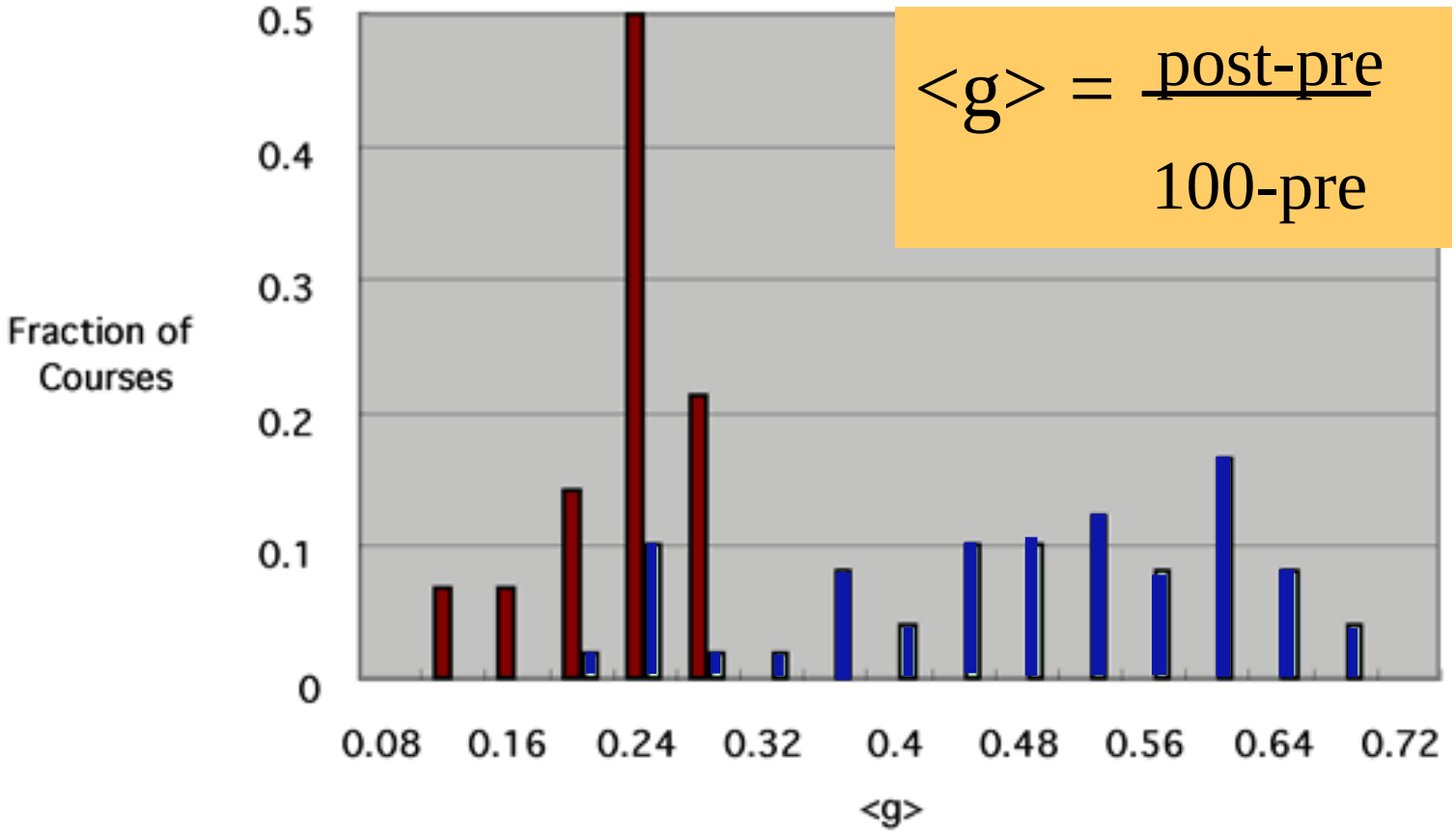
TIFF (Uncompressed) decompressor
are needed to see this picture.

by actively engaging students…

Back to the FCI

red = trad, blue = interactive engagement



$$\langle g \rangle = \frac{\text{post-pre}}{100\text{-pre}}$$

R. Hake, "…A six-thousand-student survey…" AJP **66**, 64-74 ('98).

PER Theoretic Background

Individual ← Instruction via transmission — Content (E/M)

transmissionist

Individual ↔ Construction constructivist — Content (E/M)

Prior knowledge

basic constructivist

Instructor/ Tools . . .

Individual ↔ Content (E/M)

Prior knowledge

Contextual constructivist

context

Finkelstein, N. (2005) Context in the Context of Physics Education, *IJSE*
Finkelstein, N. (2005-2009). NSF CAREER Grant: REC# 0448176

a contextual perspective

people's knowing / cognition is situated within social, cultural and historical contexts

what does this mean?

Meaning arises in context

Studying a procedure*

- arrange things into groups
- if you have to, go somewhere else due to lack of facilities
- do not overdue any endeavor
- a mistake is expensive
- manipulation of mechanisms is self-explanatory
- no foreseeable end to the necessity for this task

* Bransford, & Johnson(1972). Journal of Verbal Learning and Verbal Behavior 11, 717-726

modest reframing of class context

U. Washington Tutorials
50 min/wk, 30 students, 1 grad TA
+ **undergrad Learning Assistant**
(Weekly prep + LA seminar)

Online HW System
CAPA or MP

Phys lecture
3-600 students
3 lectures/wk
(No lab)

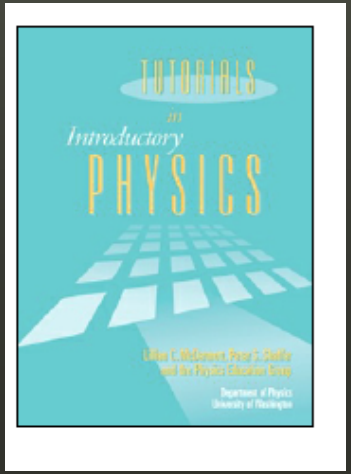
Text
trad or PER based

Interactive Lectures
Peer Instruction,
pers. resp. system

Tutorials in Introductory Physics

Reconceptualize Recitation Sections

- Materials
- Classroom format / interaction
- Instructional Role



Proven Curricula

D.E. Trowbridge and L. C. McDermott, "Investigation of student understanding of the concept of acceleration in one dimension," *Am. J. Phys.* **49** (3), 242 (1981).

D.E. Trowbridge and L. C. McDermott, "Investigation of student understanding of the concept of velocity in one dimension," *Am. J. Phys.* **48** (12), 1020 (1980)

R.A. Lawson and L.C. McDermott, "Student understanding of the work-energy and impulse-momentum theorems," *Am. J. Phys.* **55** (9), 811 (1987)

L.C. McDermott and P.S. Shaffer, "Research as a guide for curriculum development: An example from introductory electricity, Part I: Investigation of student understanding." *Am. J. Phys.* **60** (11), 994 (1992); Erratum to Part I, *Am. J.* Phys. 61 (1), 81 (1993).

P.S. Shaffer and L.C. McDermott, "Research as a guide for curriculum development: An example from introductory electricity, Part II: Design of instructional strategies." Am. J. Phys. 60 (11), 1003 (1992)

L.C.McDermott, P.S. Shaffer and M. Somers, "Research as a guide for curriculum development: An illustration in the context of the Atwood's machine," Am. J. Phys.62 (1) 46-55 (1994).

More: see http://www.phys.washington.edu/groups/peg/pubsa.html

Tutorial Materials

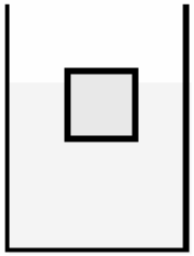
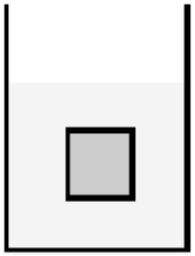
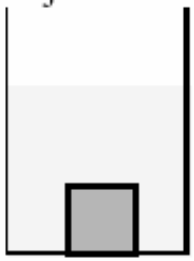
Hands-on, Inquiry-based, Guided, Research-based

Assignment 11M: Name _____

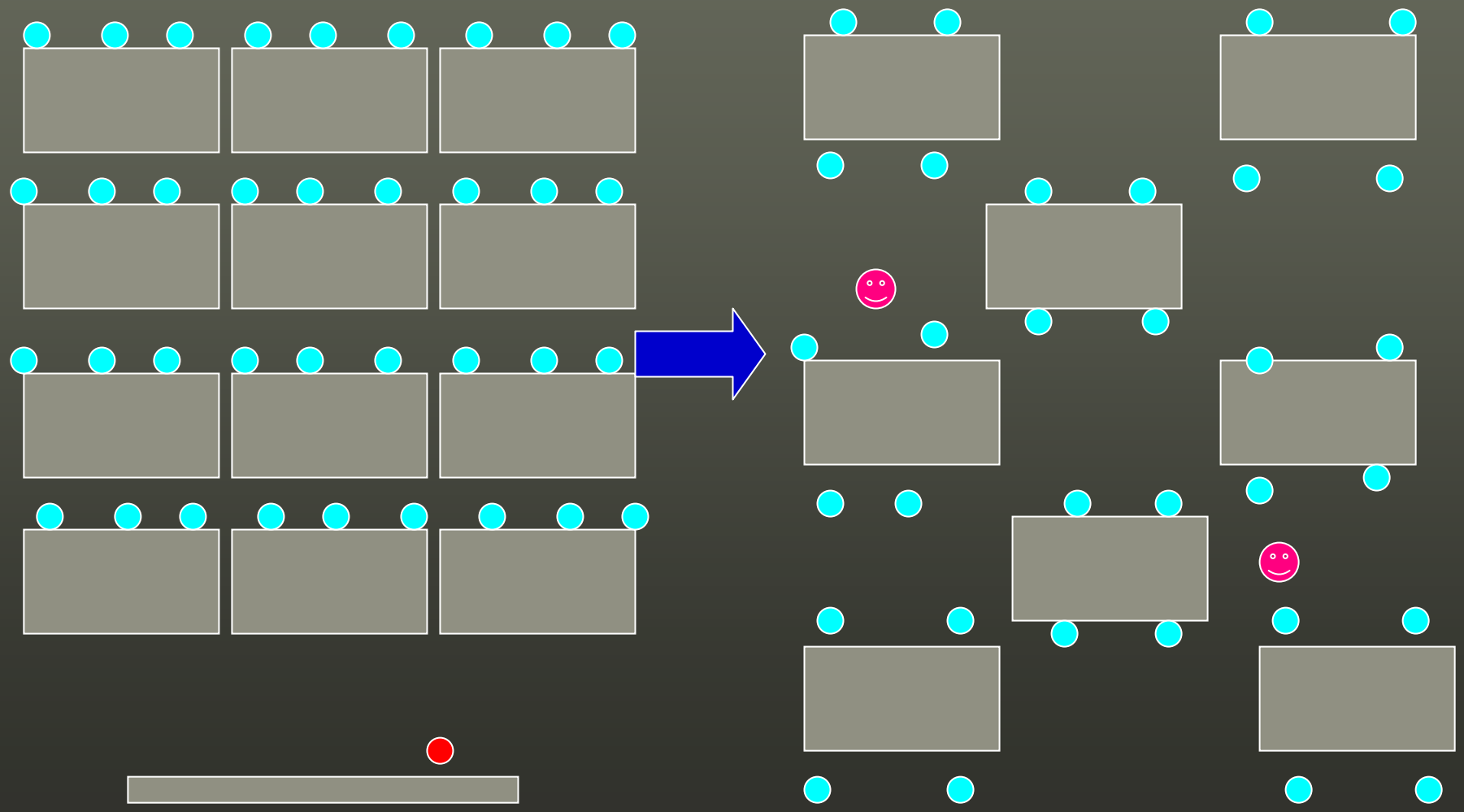
Buoyancy Tutorial section_____

1. Three 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 $m_{\text{object}} \begin{pmatrix} > \\ < \\ = \end{pmatrix} m_{\text{displaced water}}$?	Is $m_{\text{object}} \begin{pmatrix} > \\ < \\ = \end{pmatrix} m_{\text{displaced water}}$?	Is $m_{\text{object}} \begin{pmatrix} > \\ < \\ = \end{pmatrix} m_{\text{displaced water}}$?
Explain	Explain	Explain

Tutorial vs. Trad'l Recitation



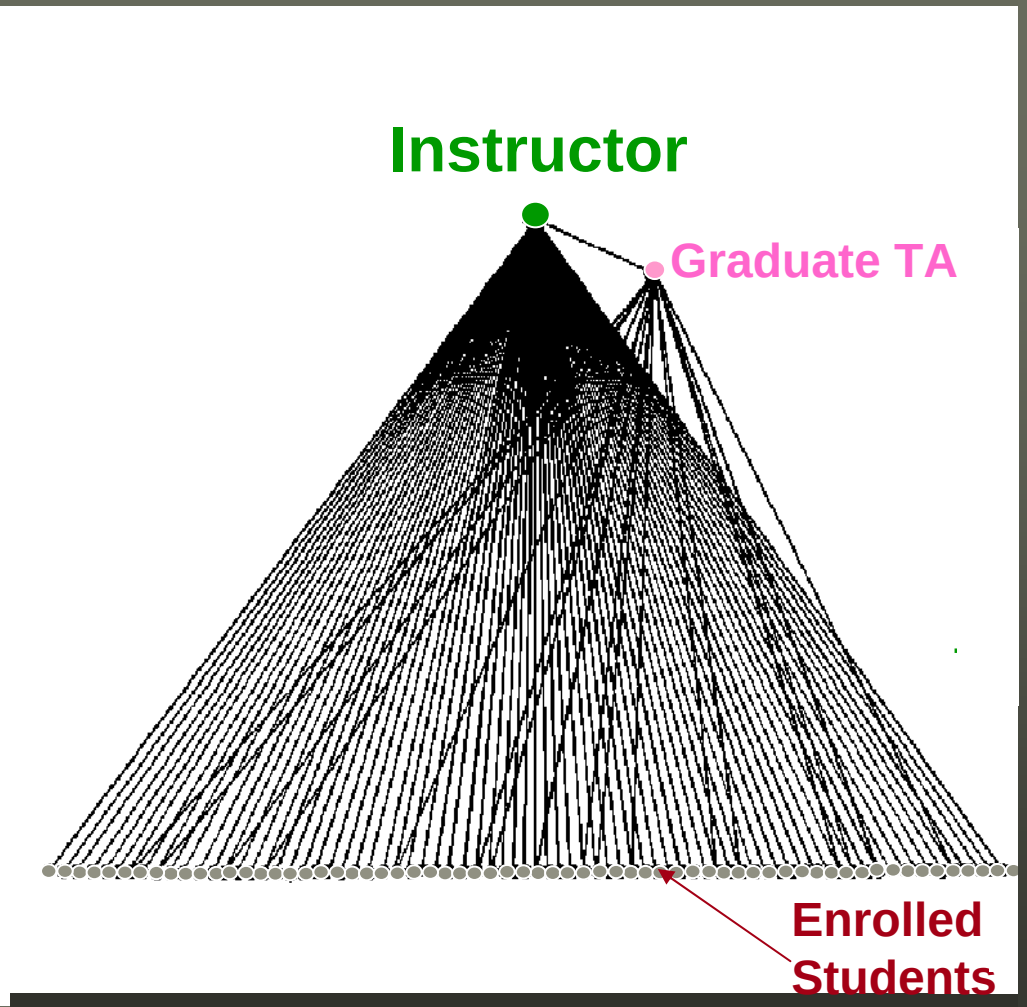
CU Model of Teacher Prep

- Begin *within* physics department
- Learning Assistants:

  Use UG's to implement PER-based materials
  - Model best-practices for all students
  - Improve education of all students
  - Increase likelihood students engage in teaching
- Improve content mastery of future teachers

V. Otero, N.D. Finkelstein, S.J. Pollock and R. McCray (2006). *Science*, **313**, 445

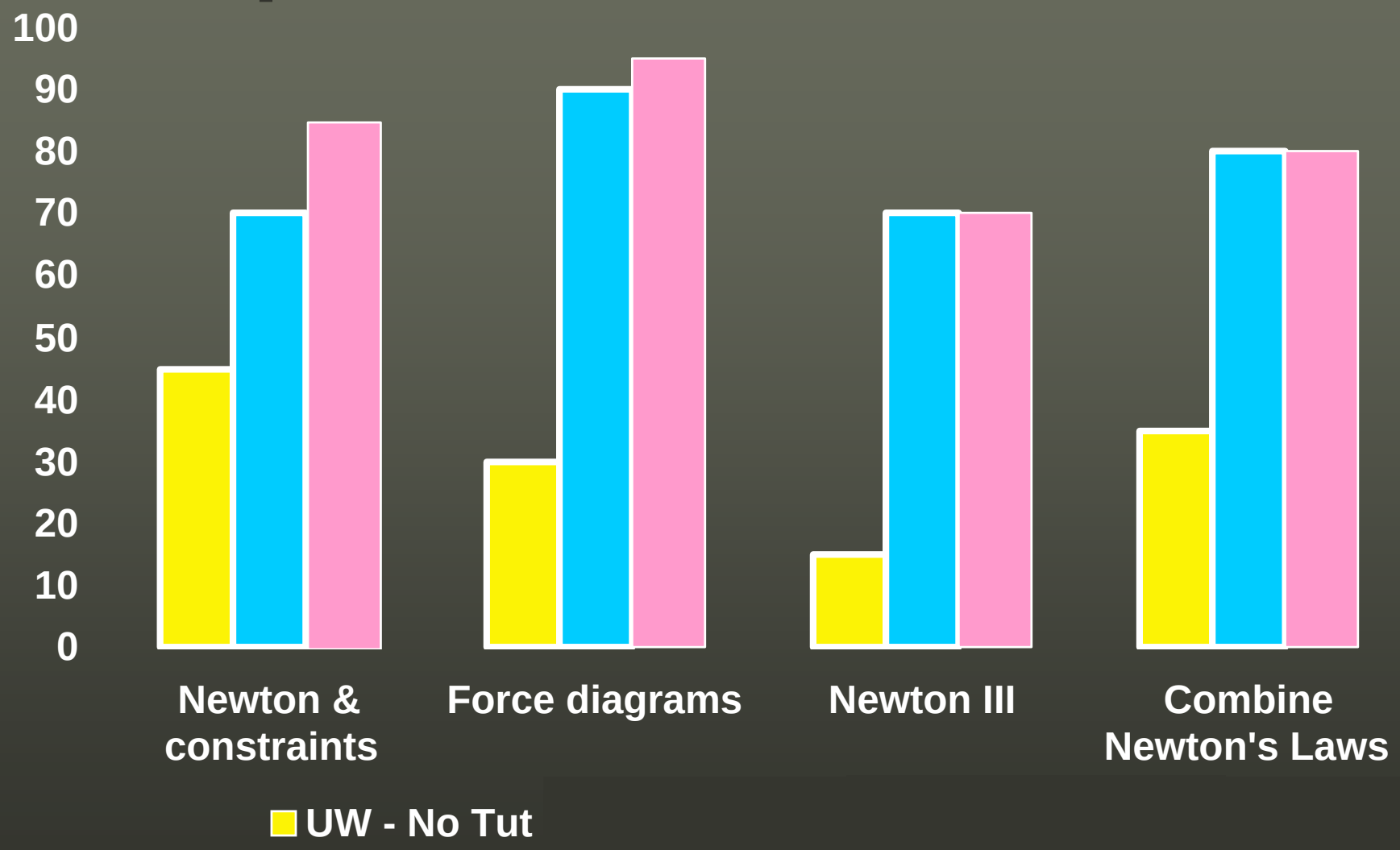
Modifying Course Structure



Traditional Large Enrollment Course

V. Otero, N.D. Finkelstein, S.J. Pollock and R. McCray (2006). *Science*, **313**, 445

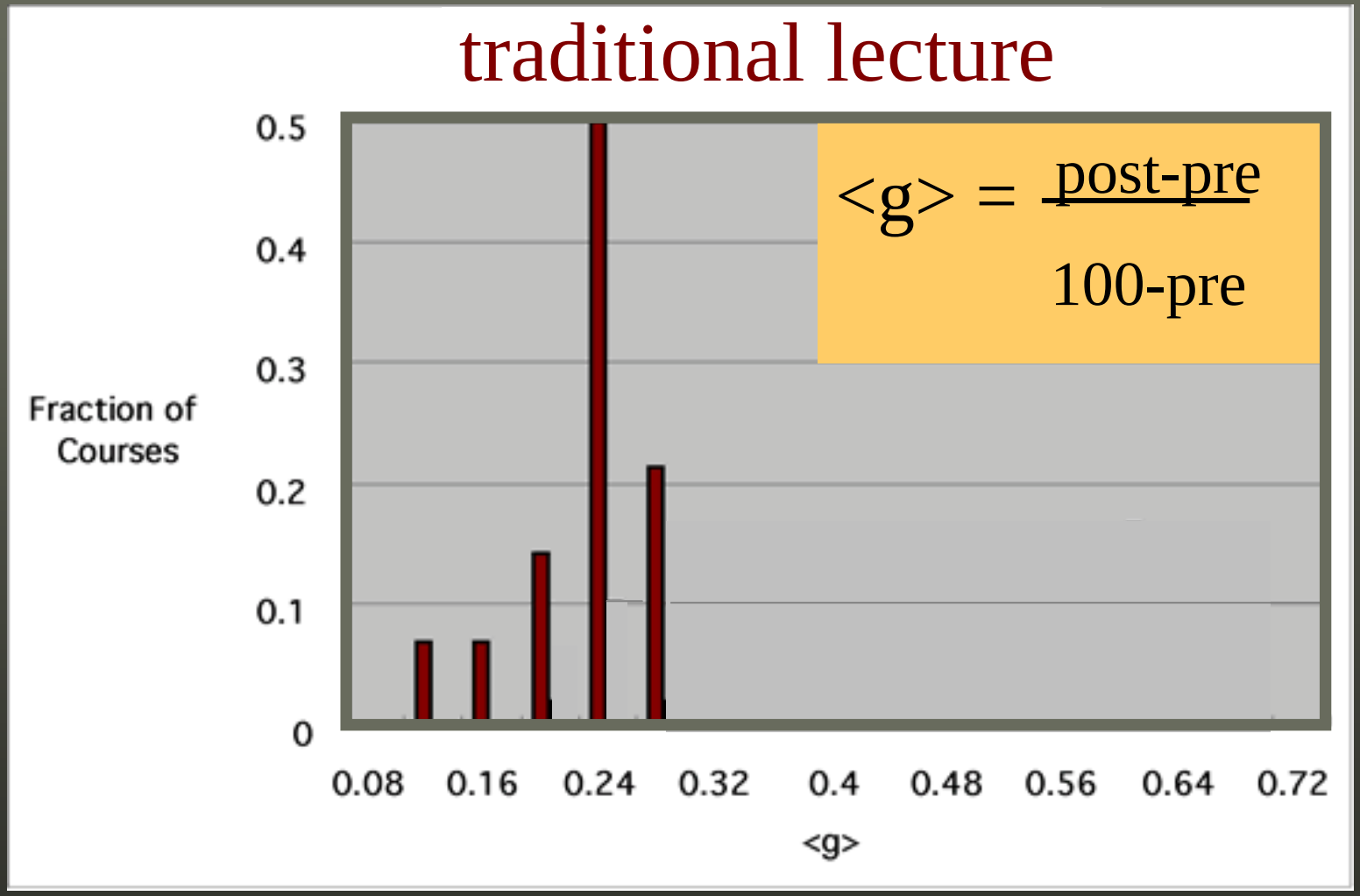
Impact and Reproducibility



Trowbridge and McDermott," *Am. J. Phys.* **49** (3), 242 (1981).

Finkelstein and Pollock, (2005). *Phys Rev ST PER*, 1,1.010101

Force Concept Inventory



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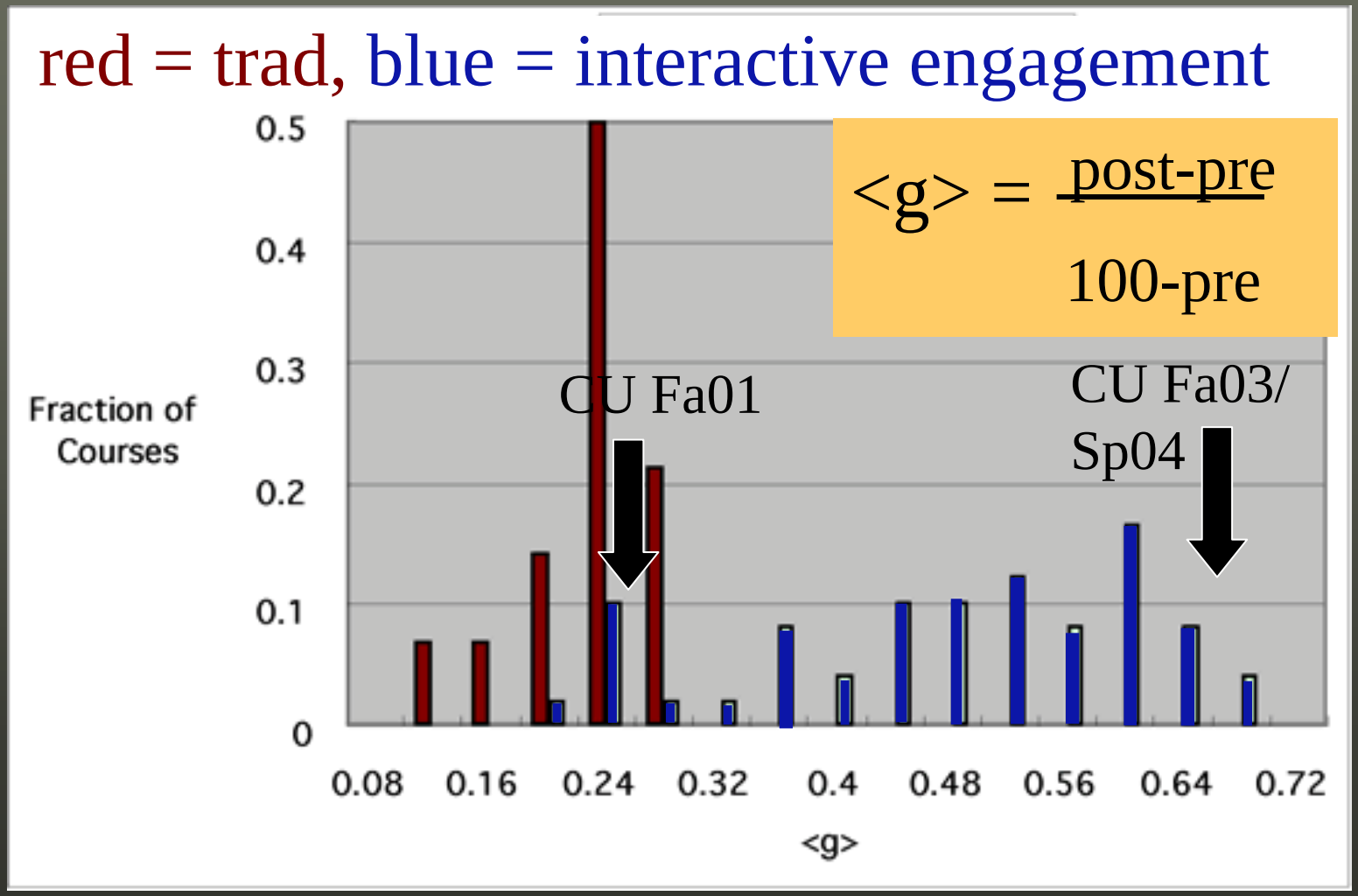
Force Concept Inventory



R. Hake, "…A six-thousand-student survey…" AJP **66**, 64-74 ('98).

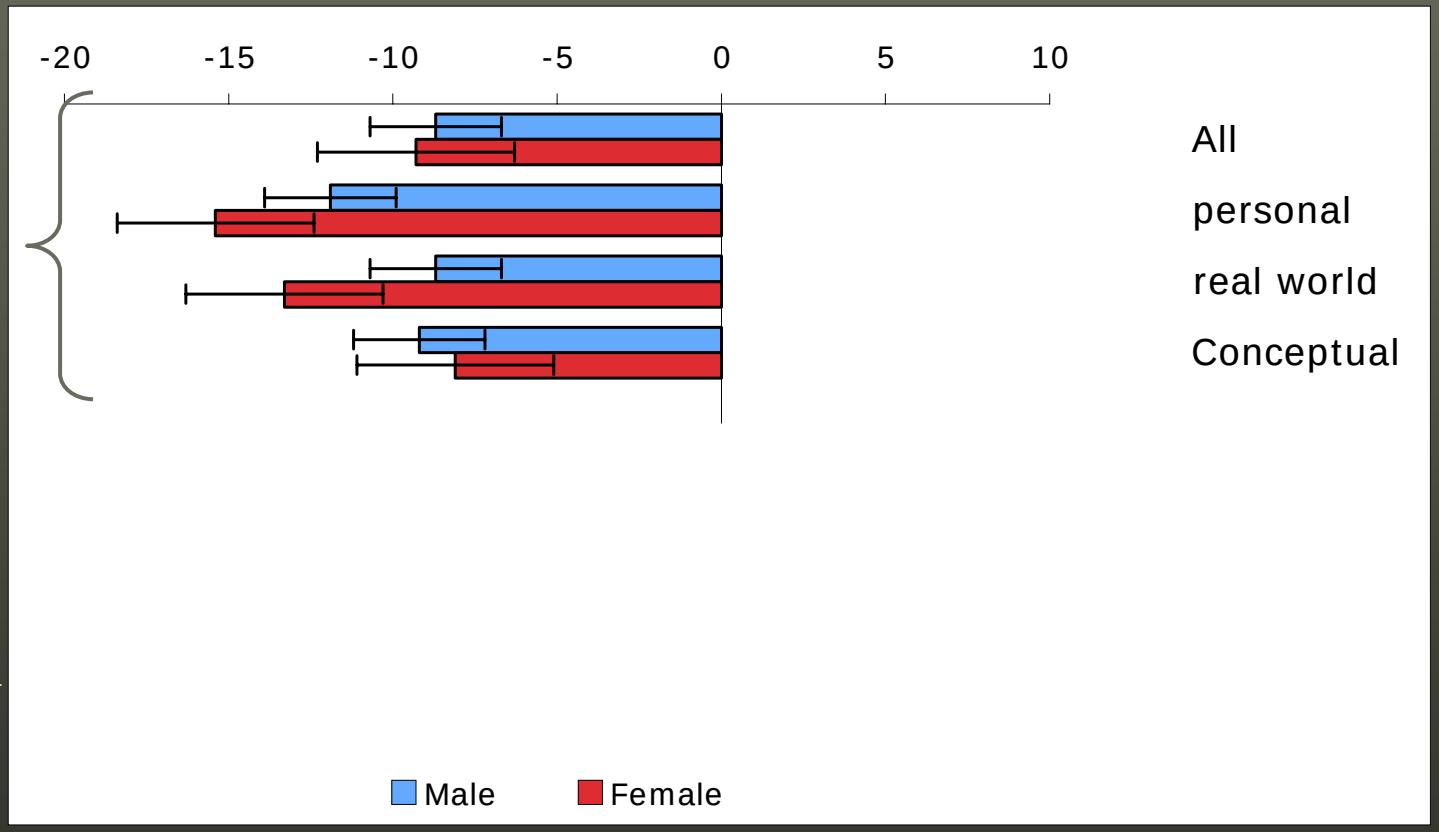
Attitudes & Beliefs

CLASS shifts (post-pre)
End of Term Survey

CLASS shifts (post-pre)

CU
Partly trad

CU
Reformed
(some attention
to A&B)



perhaps success is not so simple…

The impact of recitation/pedagogy

Physics 1, 300+ students,

***Peer Instruction* in lecture, and:**

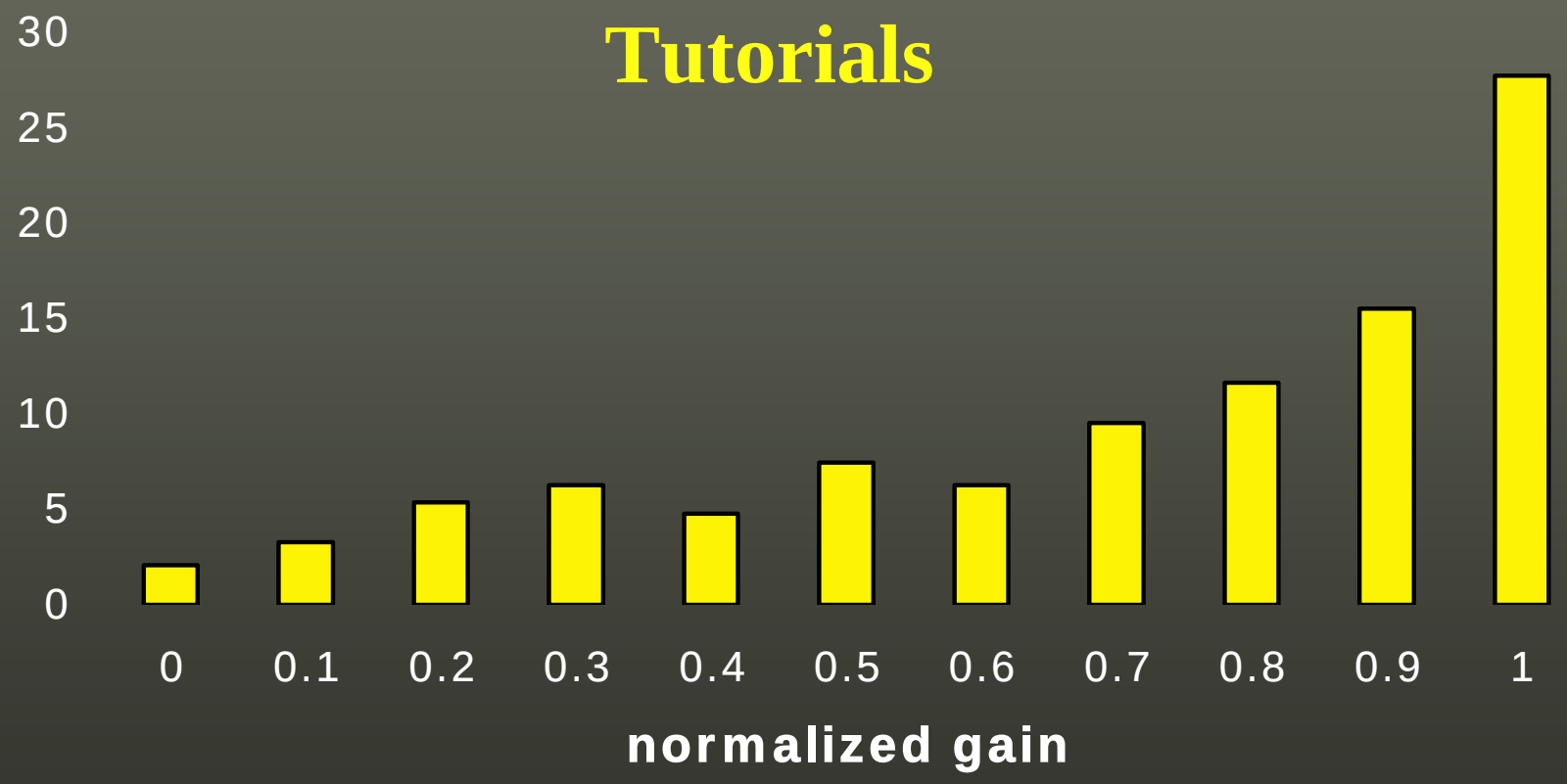
1: "Tutorials" (Sp04) *Tutorials*

2: "Workbook" (Fa04) *Knight Workbook*

3: "Traditional" (Sp05) Mostly traditional

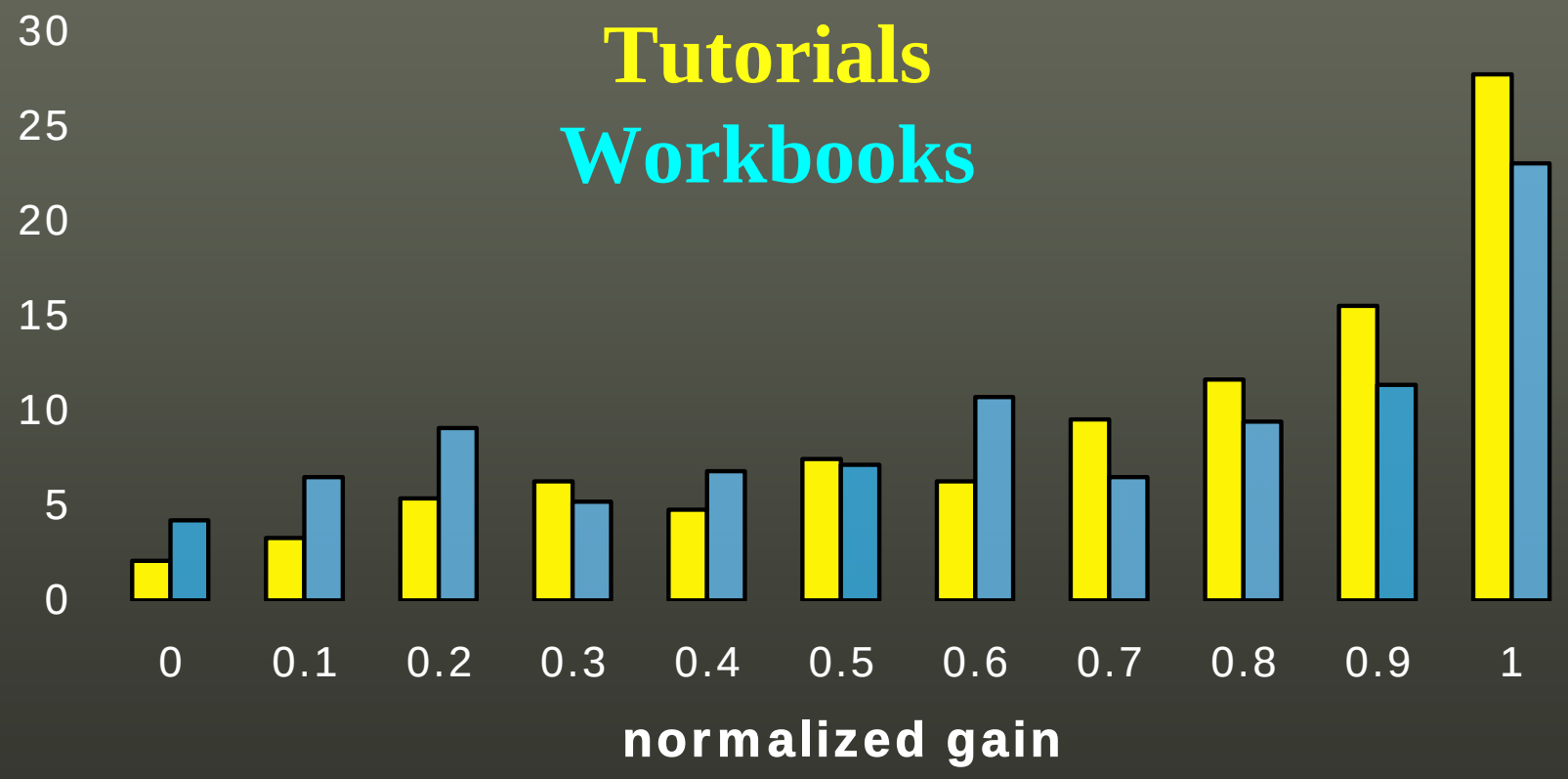
Phys 1110 normalized gains

gain <g>
= .66 +/-.02

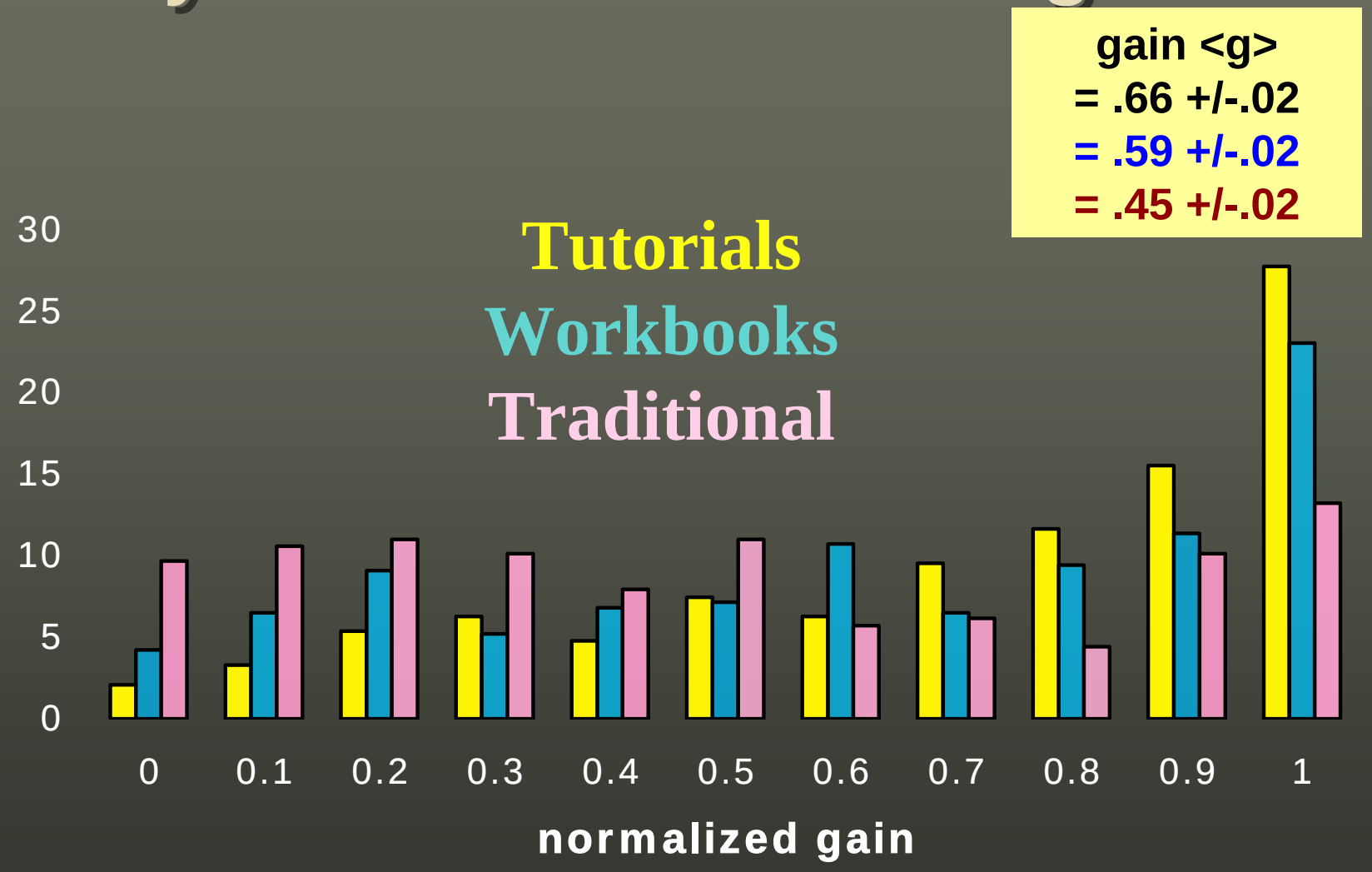


Phys 1110 normalized gains

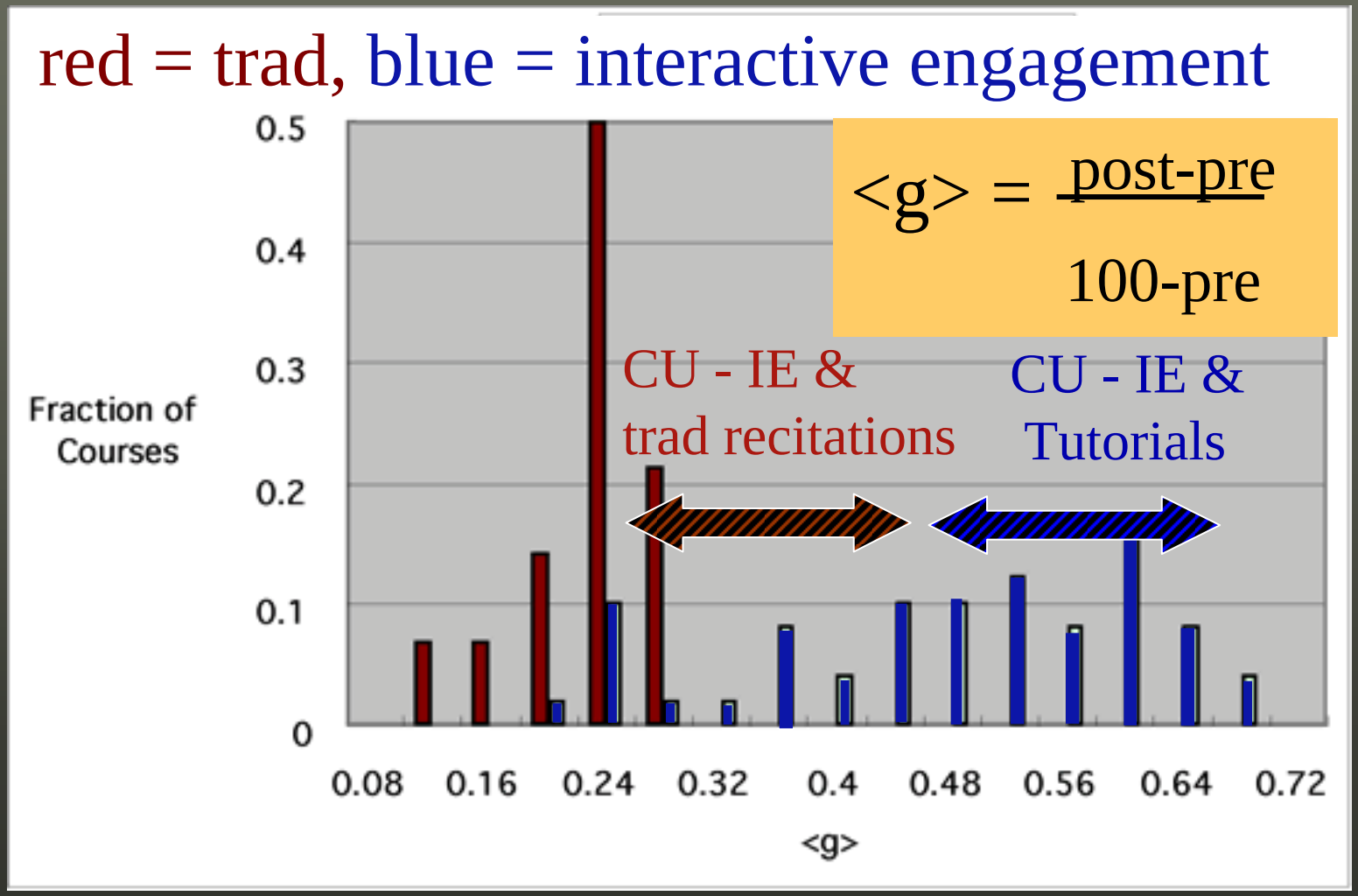
gain <g>
= .66 +/-.02
= .59 +/-.02



Phys 1110 normalized gains



Force Concept Inventory

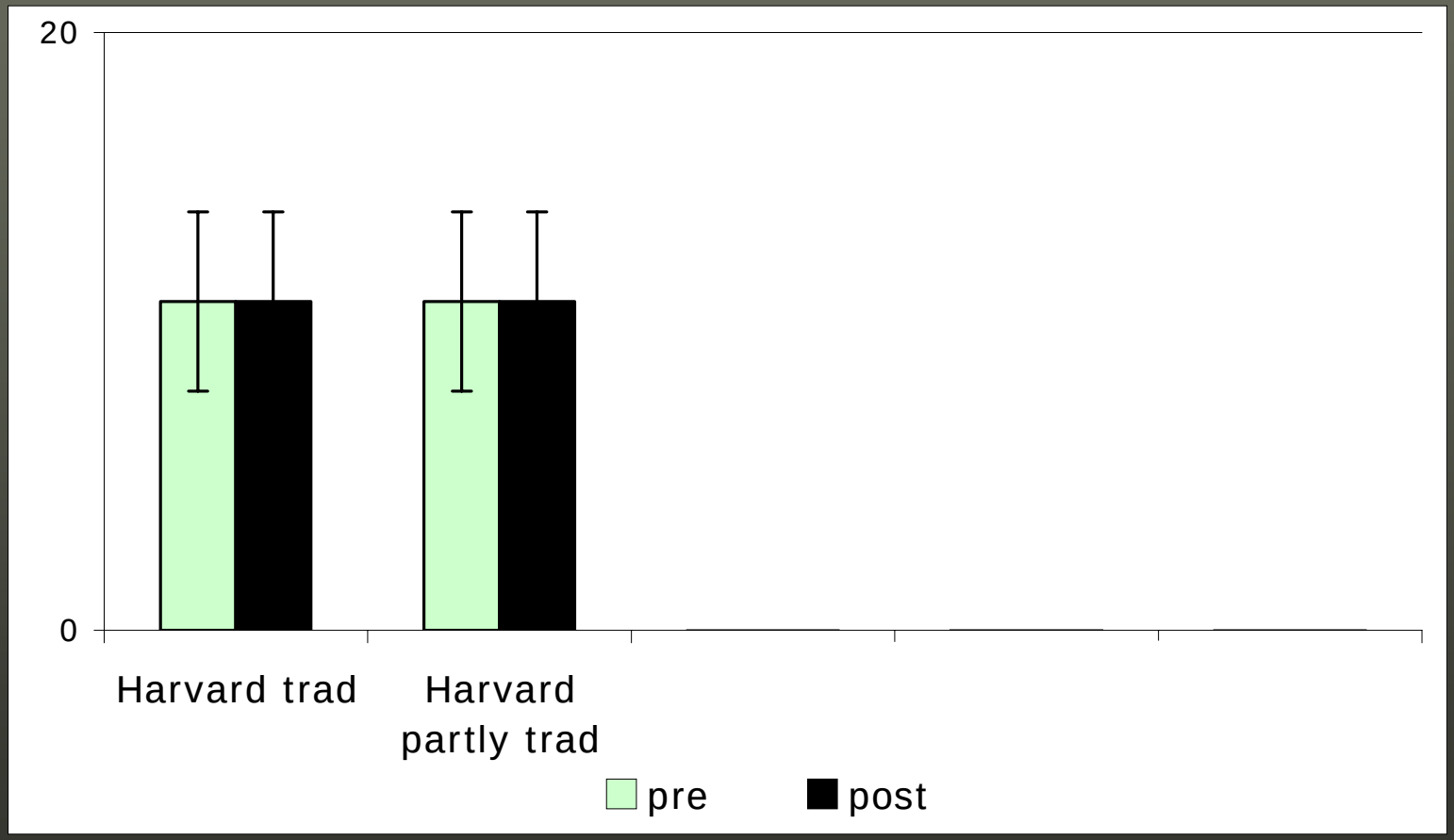


R. Hake, "…A six-thousand-student survey…" AJP **66**, 64-74 ('98).

Strong indication:
CURRICULA matters

Gender Studies

Gender difference on FCI scores



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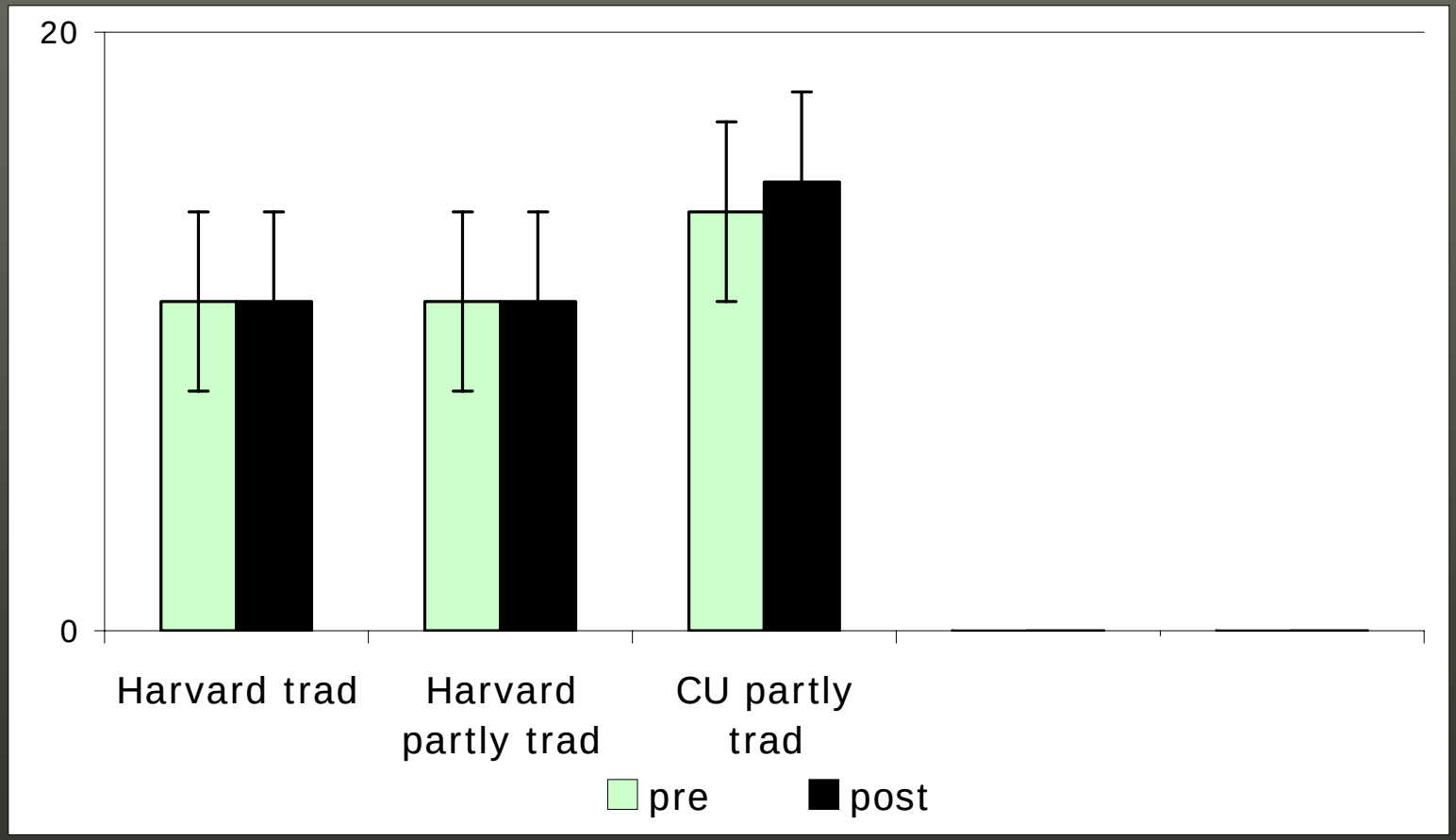

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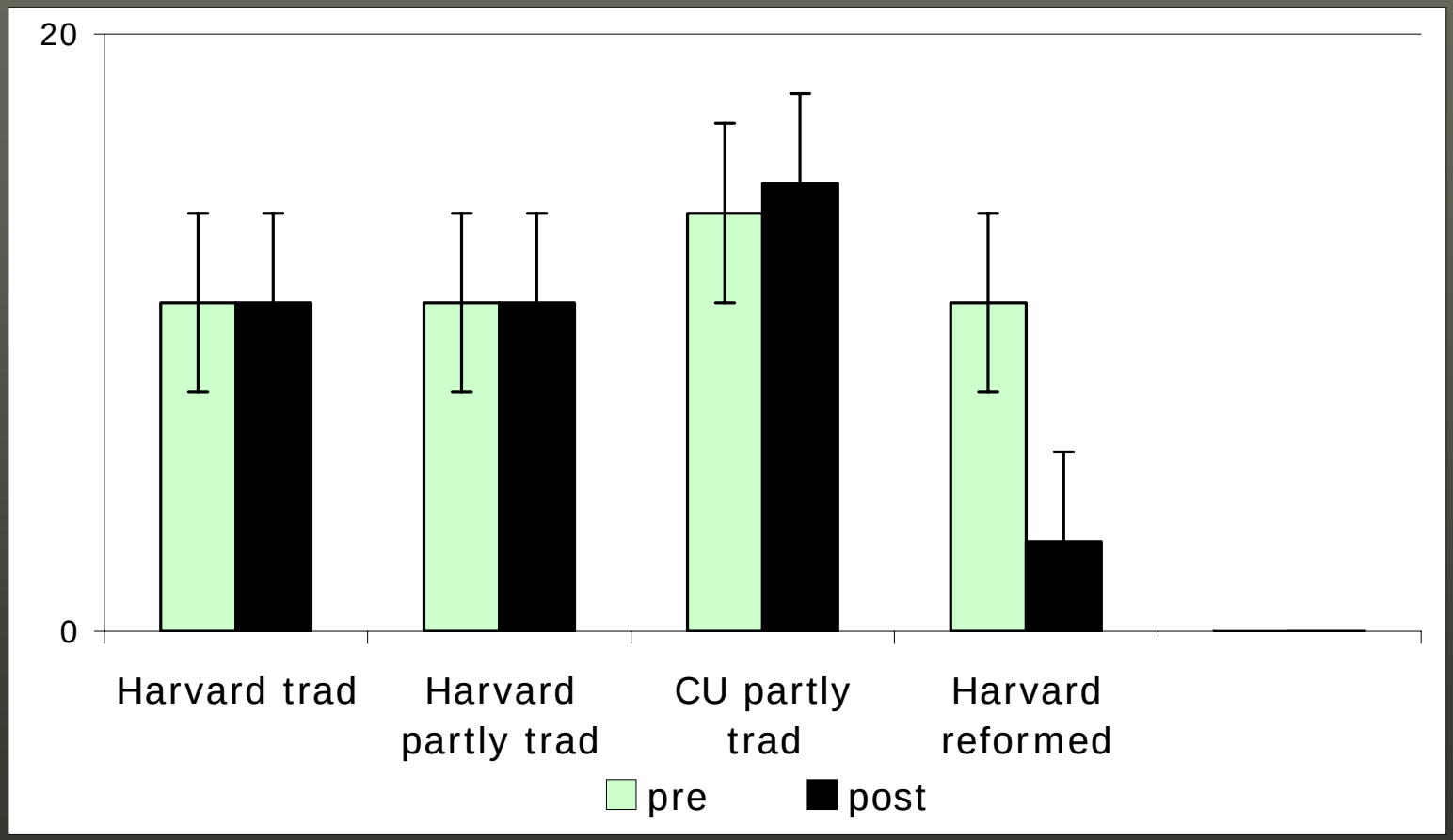
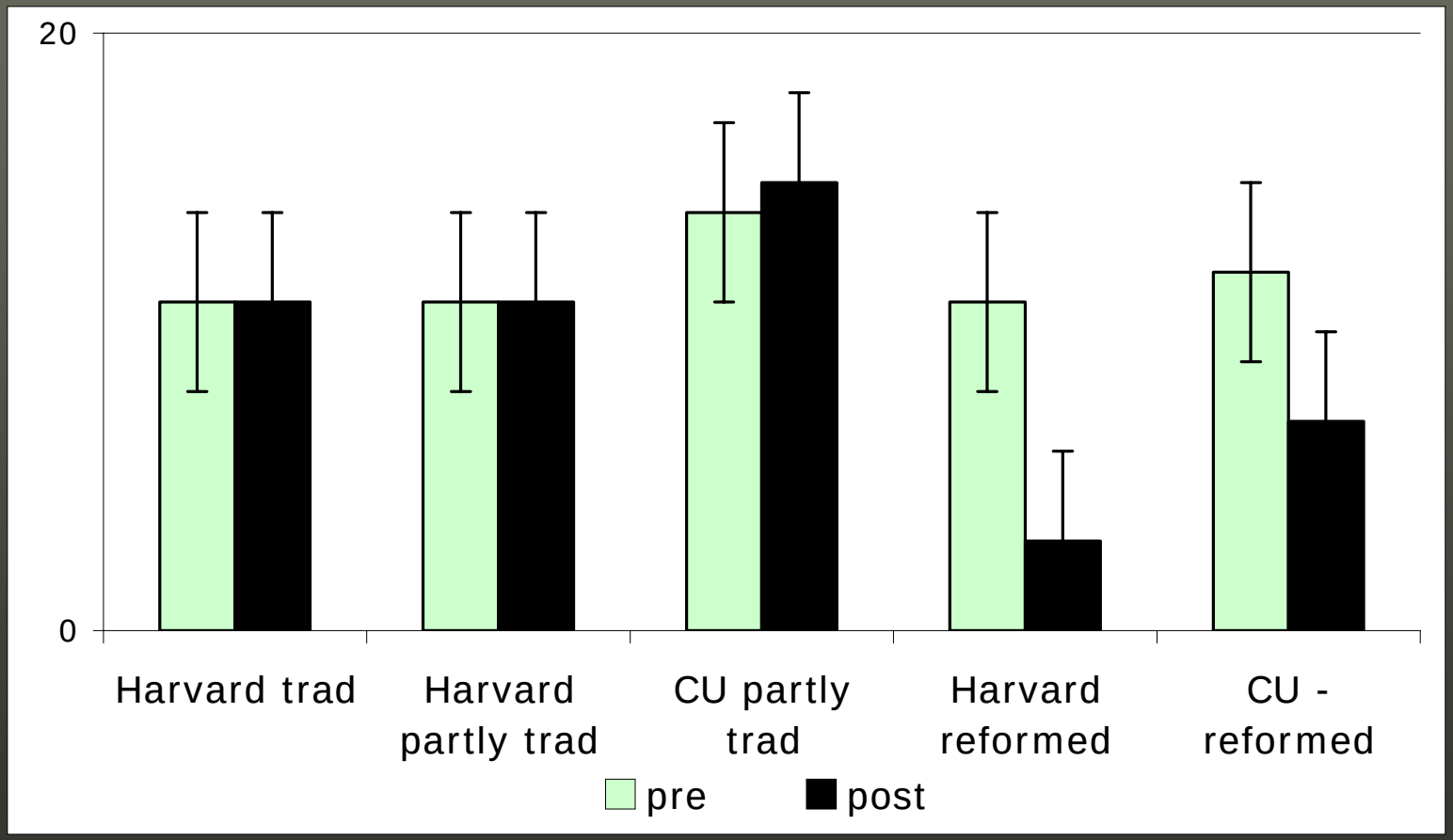
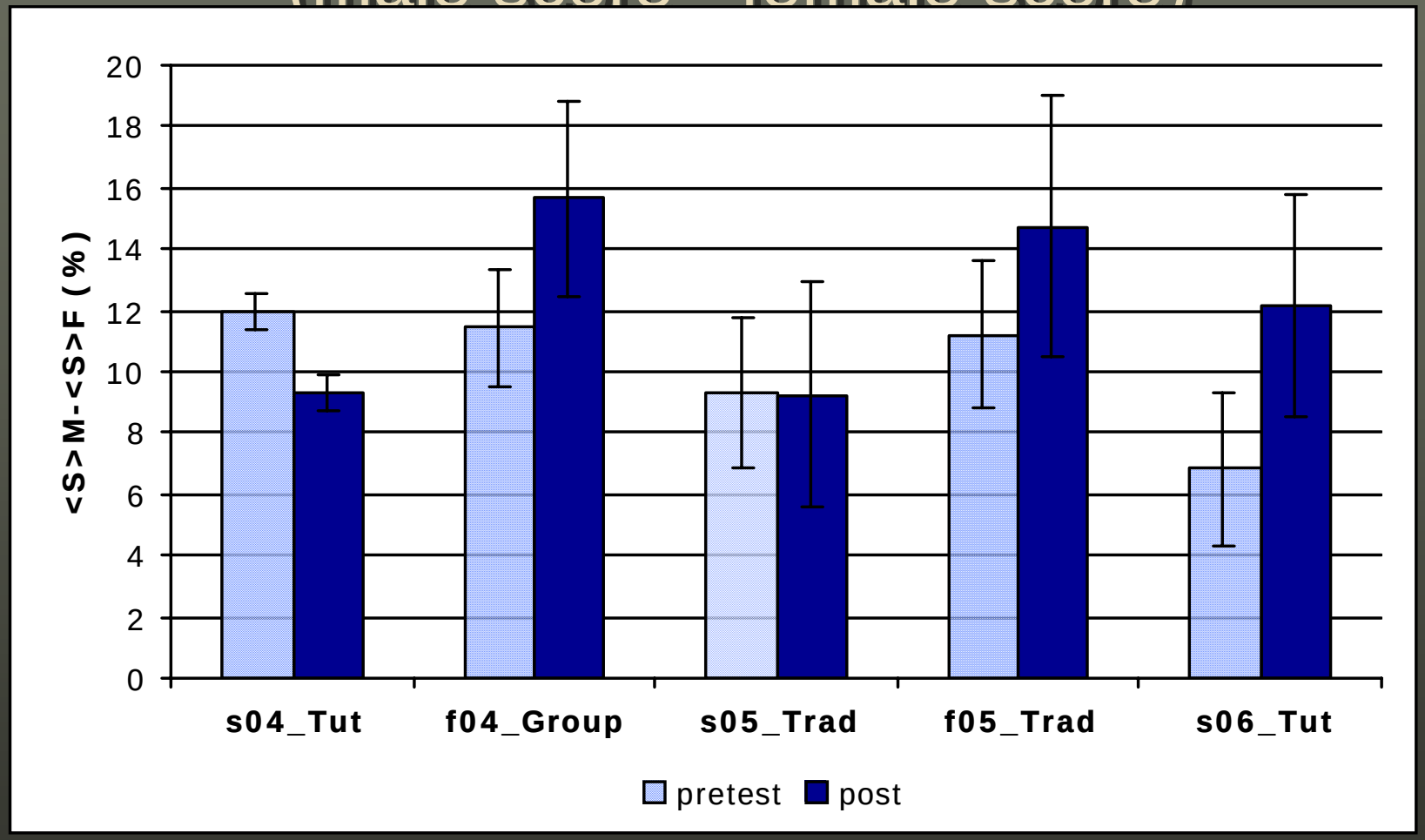


Lorenzo, Crouch, Mazur, AJP 74(2), 118-122 (2006).

Gender difference on FCI scores

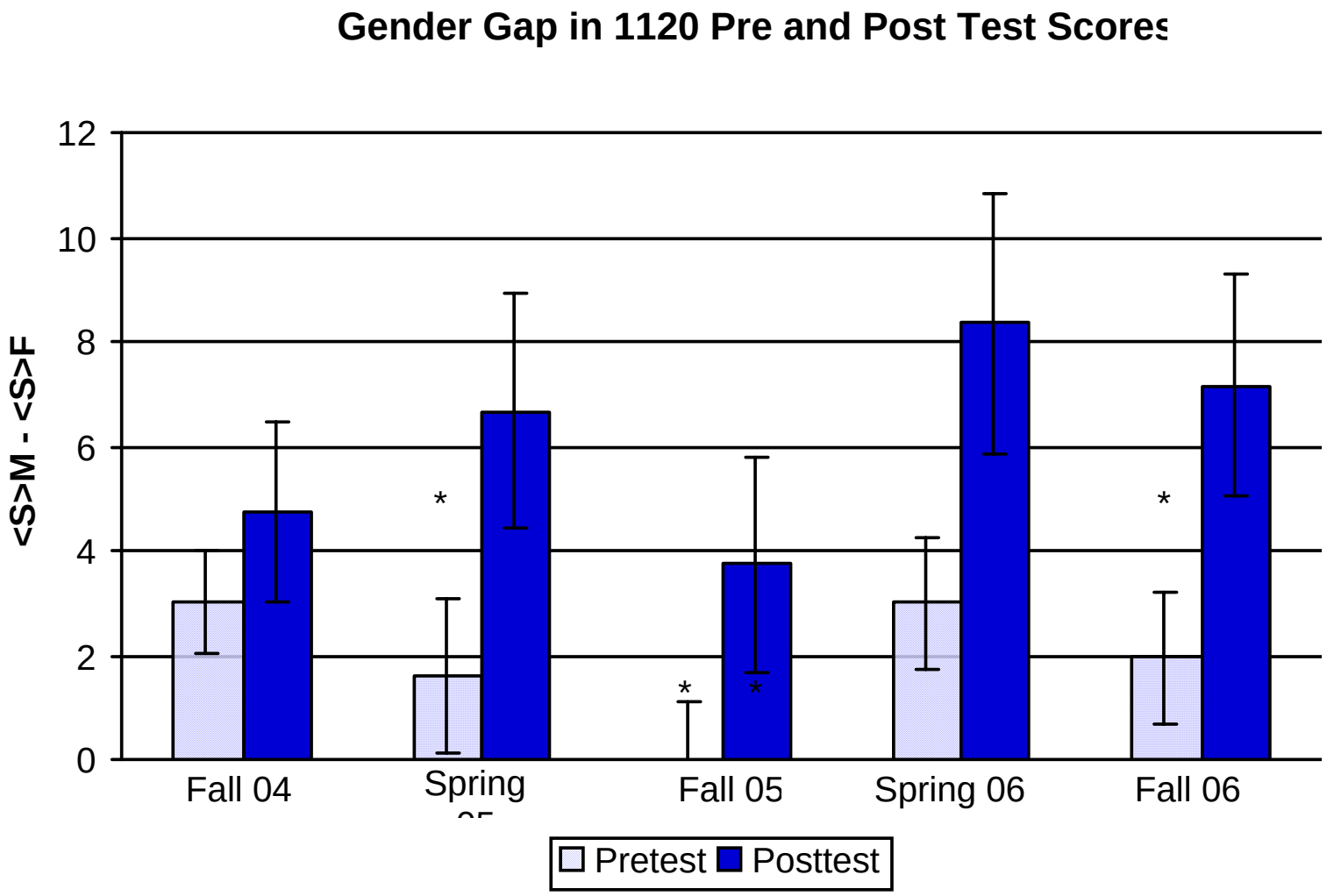


Gender Gap (FMCE)
(male score - female score)



S.J. Pollock, N.D. Finkelstein, L.Kost, “On reducing the gender gap in the physics classroom,” (in press) Physical Review, ST: PER

Gender gap (BEMA)

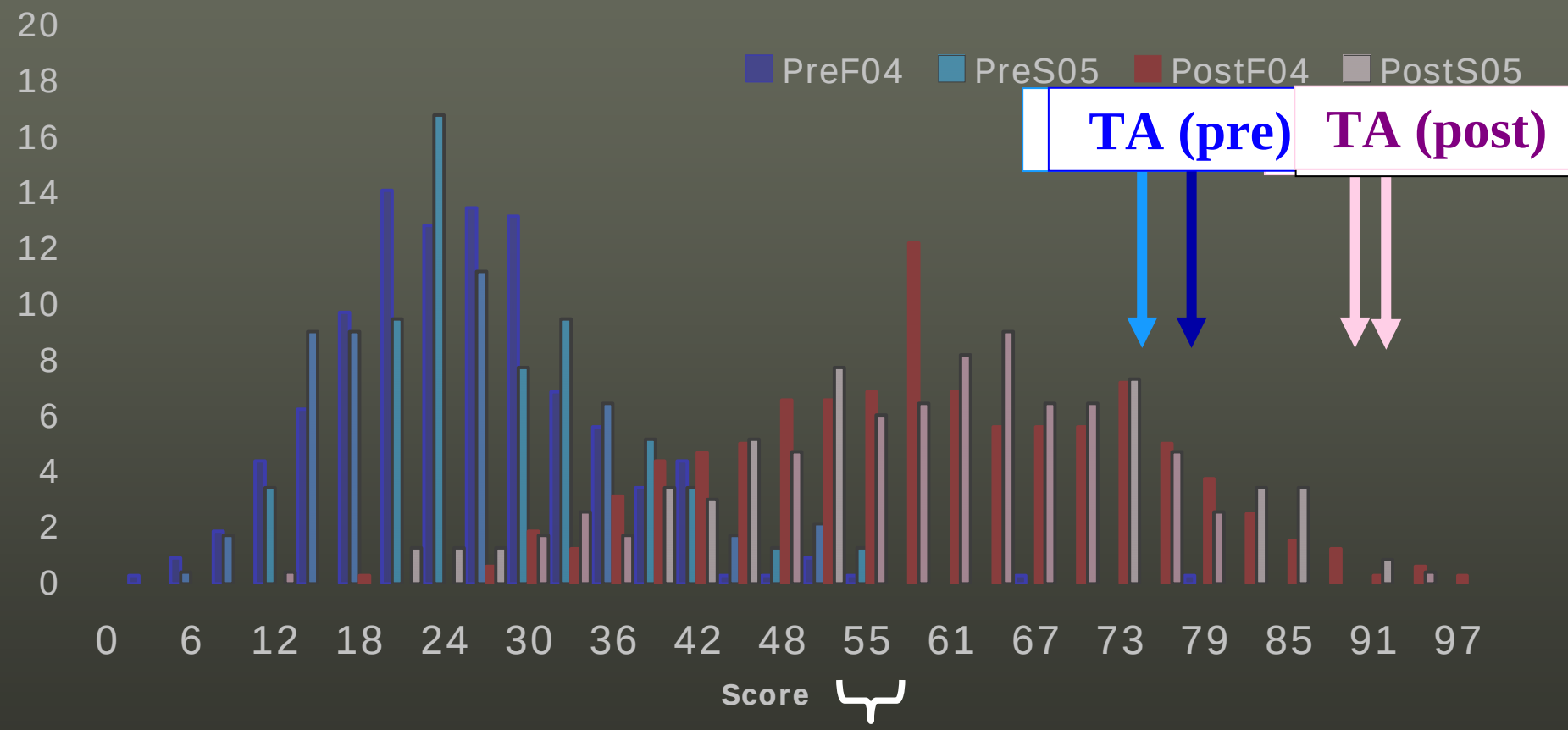


Transformed Pedagogy: *PER-based techniques necessary but not sufficient*

S.J. Pollock, N.D. Finkelstein, L.Kost, “On reducing the gender gap in the physics classroom,” (in press) Physical Review, ST: PER

Learning by Teaching: the LA Story

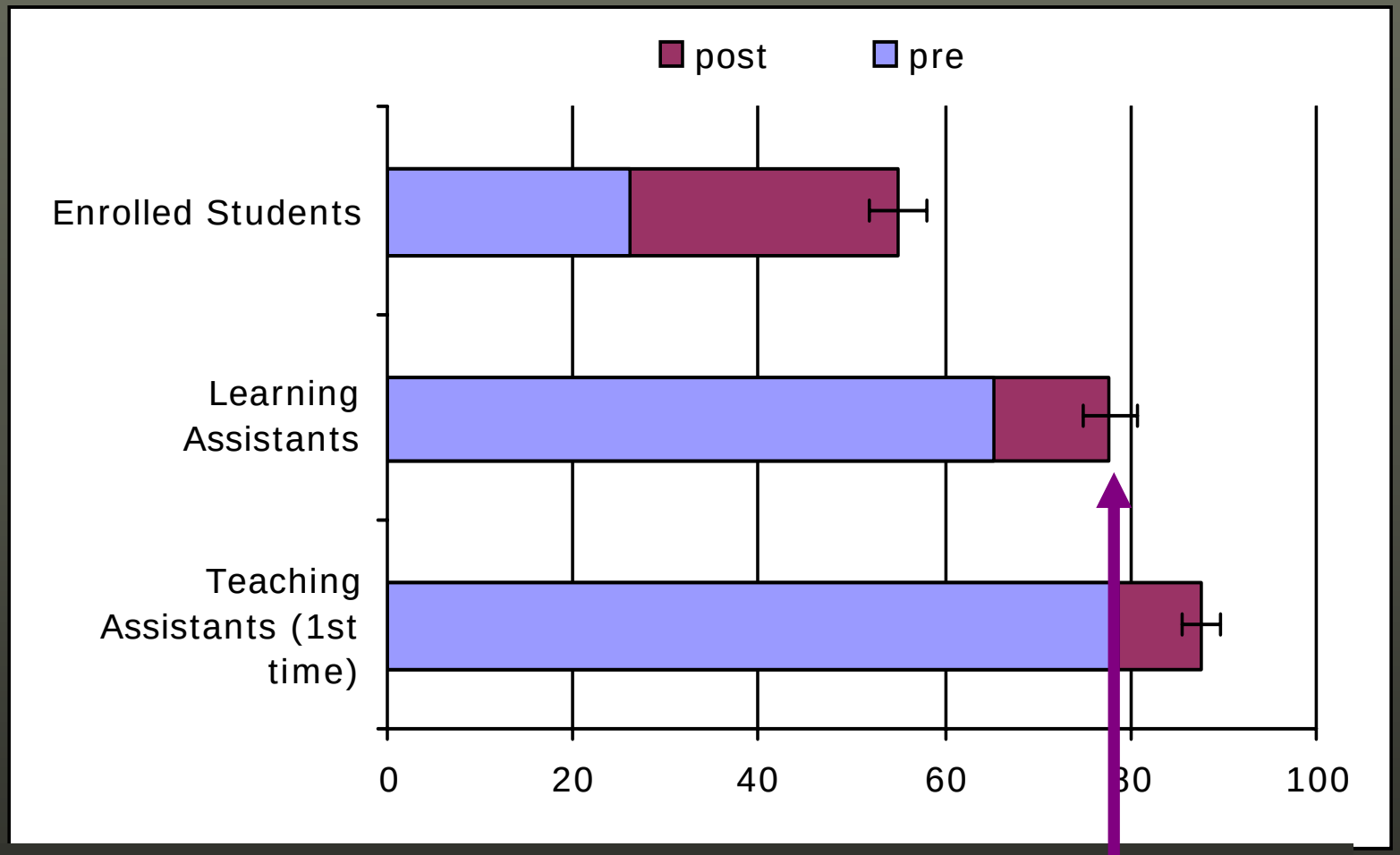
1120 BEMA LA's



CU upper division (trad)

V. Otero, N.D. Finkelstein, S.J. Pollock and R. McCray (2006). *Science*, **313**, 445

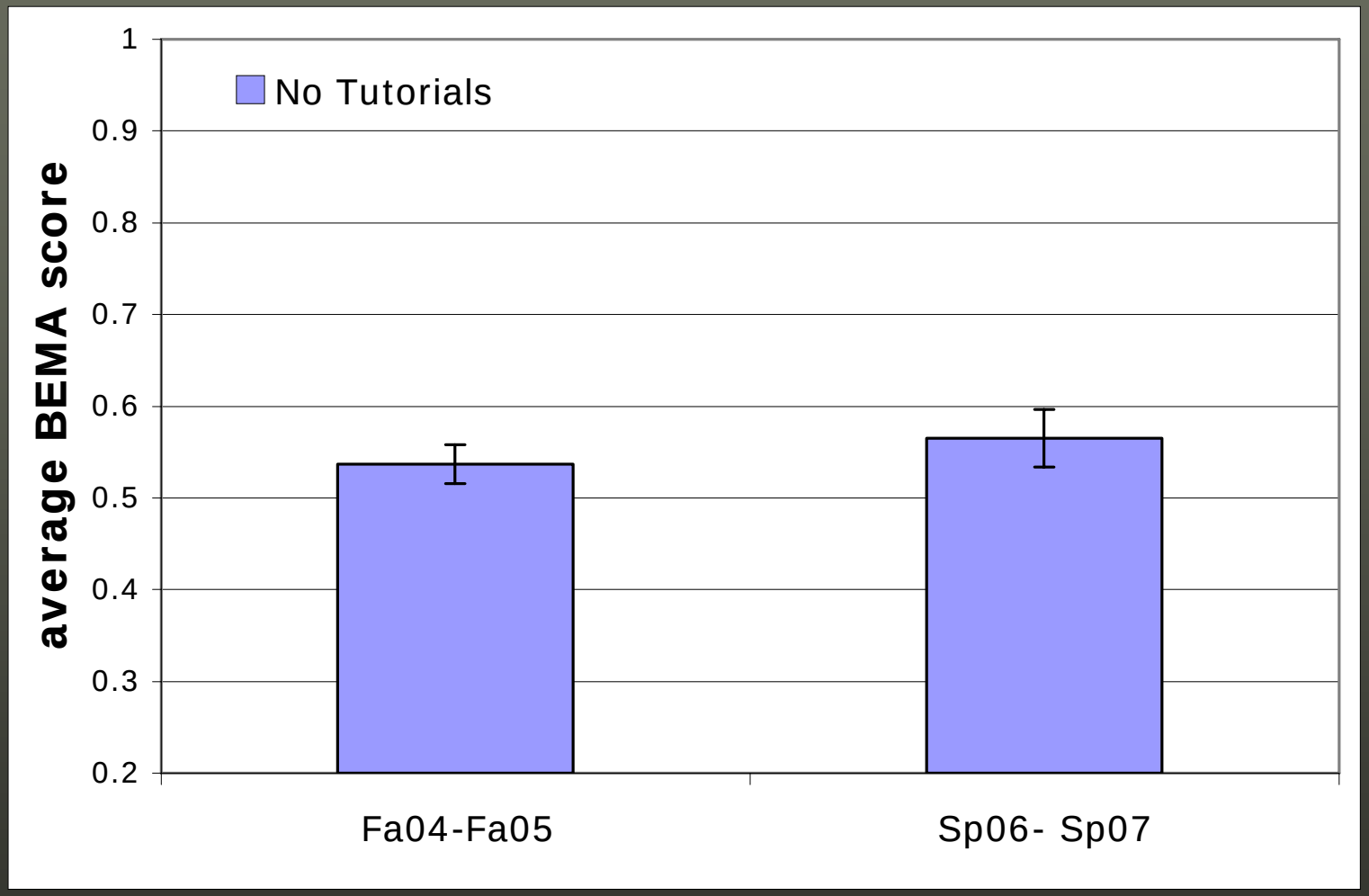
Learning gains for LAs and TAs



LAs leave at incoming TA level!

Lasting Impacts (preliminary) Longitudinal Studies

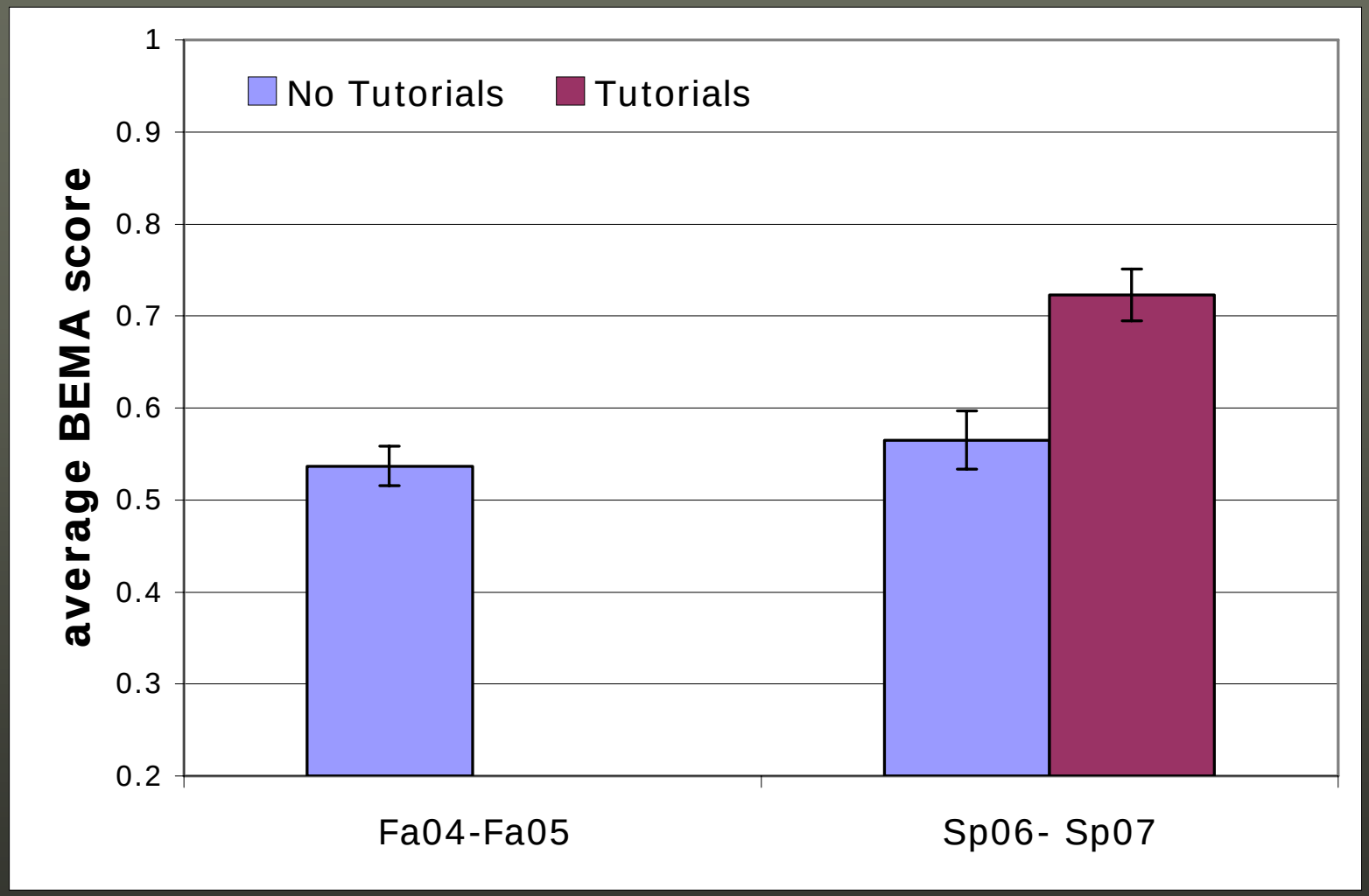
How Junior level E&M fair on BEMA?



After completing Jr Level E/M (3310 or 3320)

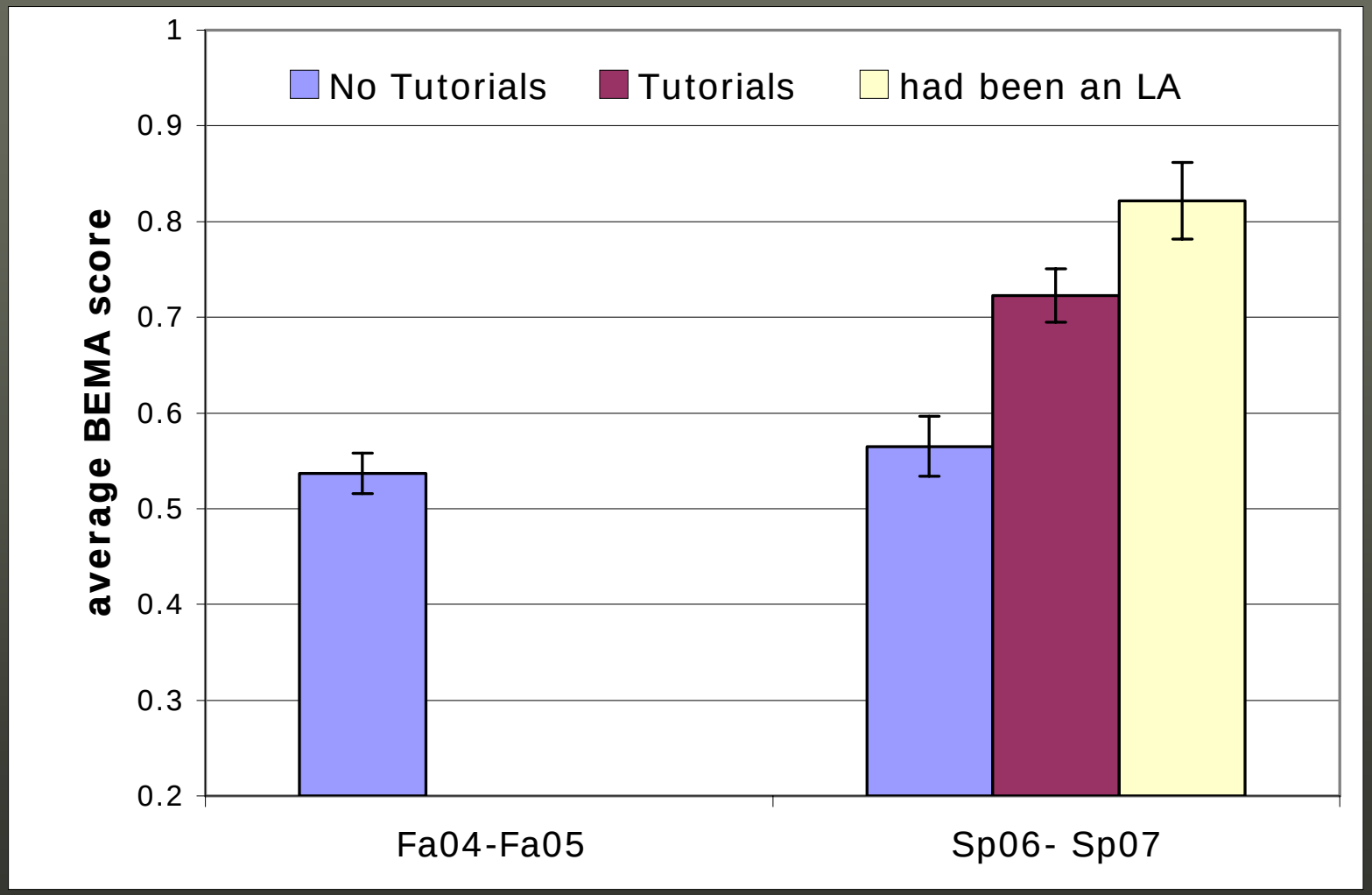
Only students who took Phys 2 (1120) *without* Tutorials

Impact of Tutorials



Red bins: students who had taken Freshman physics (1120) *with* Tutorials (~2 years prior)

Impact of LA experience



Beige: students who had been 1120 LAs

Strong indication:
CONTEXT matters

actively engaging is important

what people know affects what they learn

contexts shape what students learn (content and beliefs)

teaching is effective for instructor learning

Conclusions

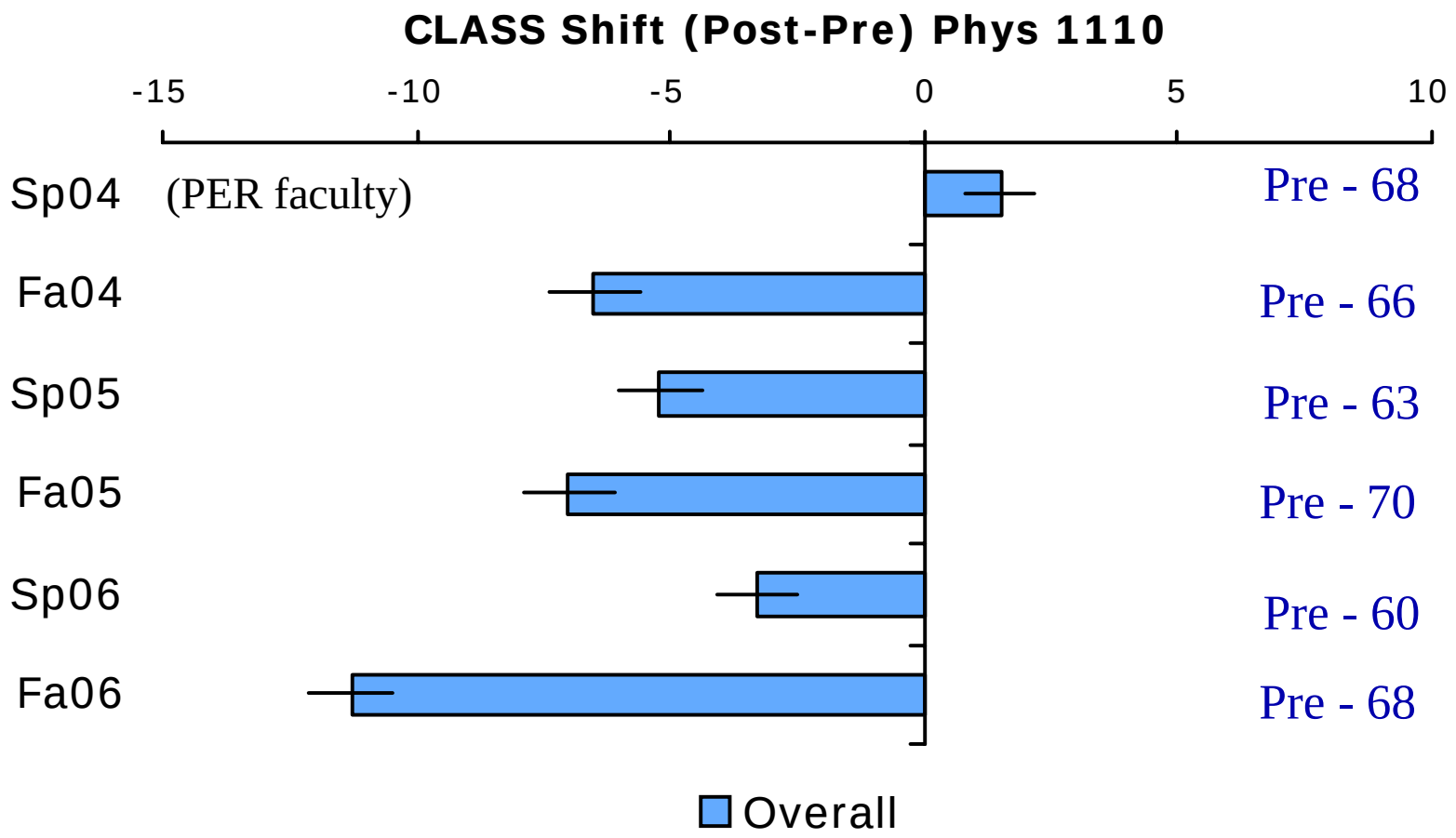
- Educational practice is a researchable endeavor
  - We can make systematic progress
  - Imperative to include physicists
- Pos[illegible]ts
- CU[illegible]
  - R[illegible]
  - Education and physics
- Sustaining & Scaling reforms is possible
  - Requires theoretical framing
  - Both CONTENT and CONTEXT matter

It's not about our teaching, it's about student learning

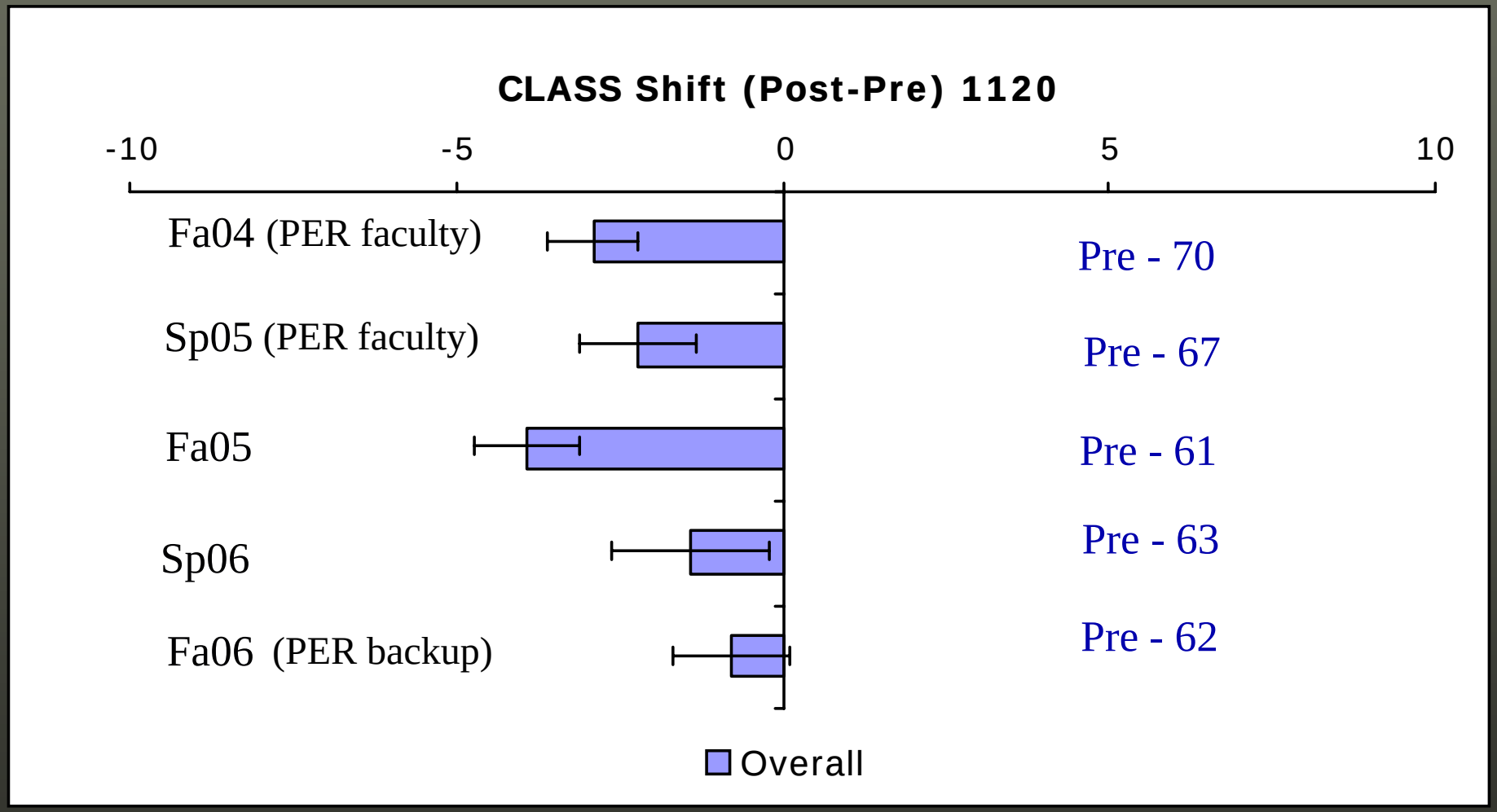
Fin

Much more at: *per.colorado.edu*

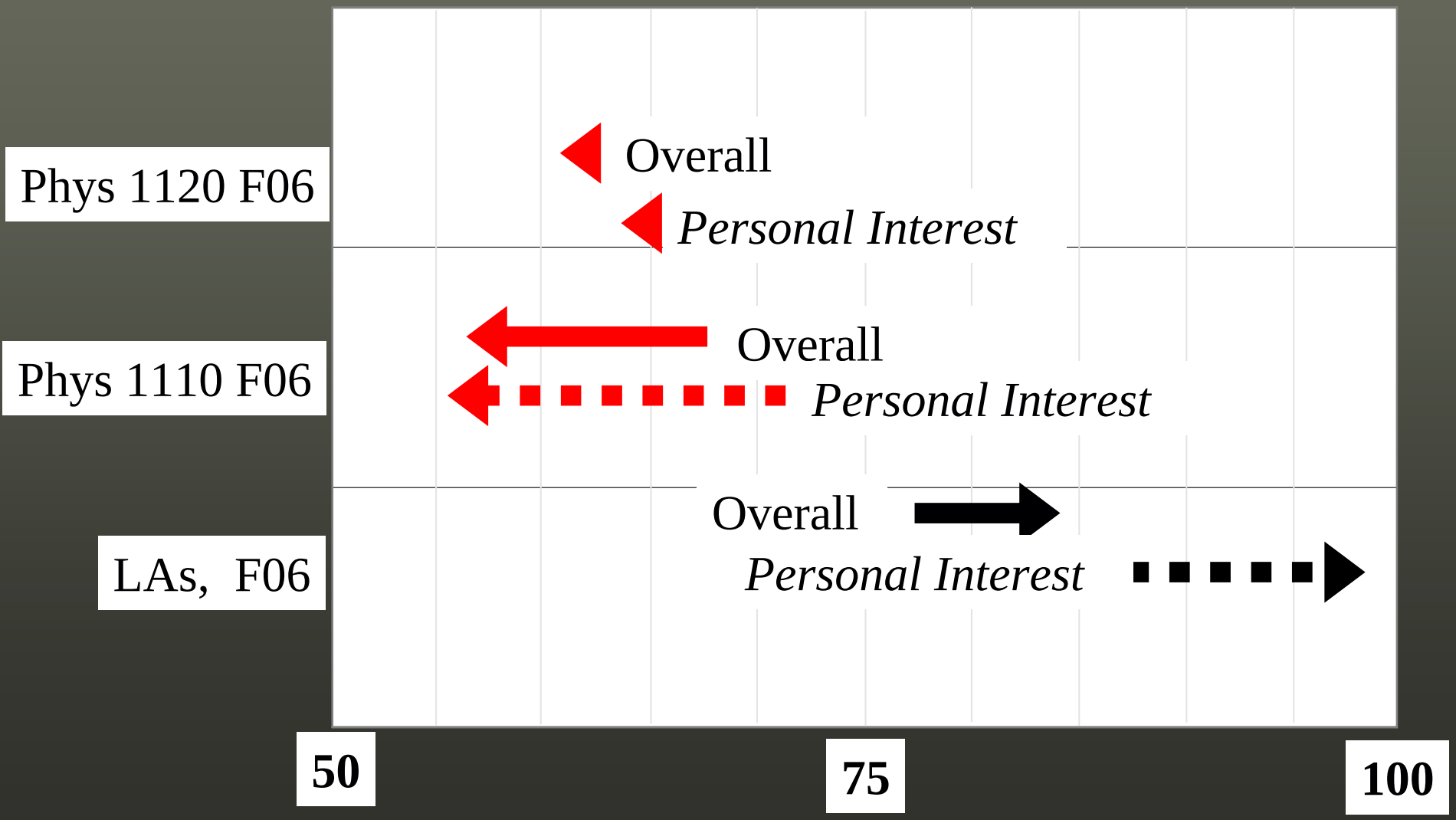
CLASS - last 6 terms (1110)



CLASS - last 6 terms (1120)

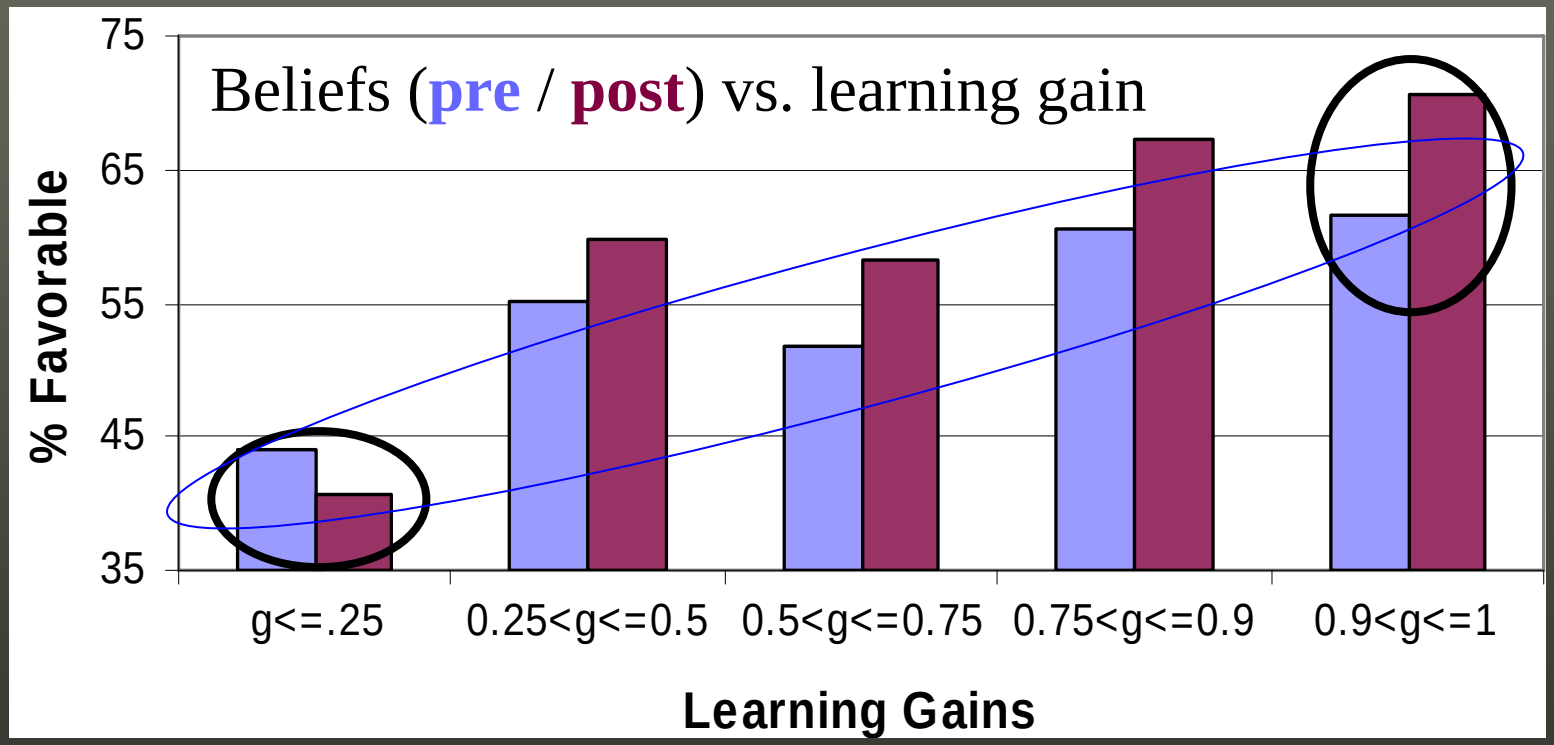


CLASS F06: Comparing students & LA's



CLASS and learning gains

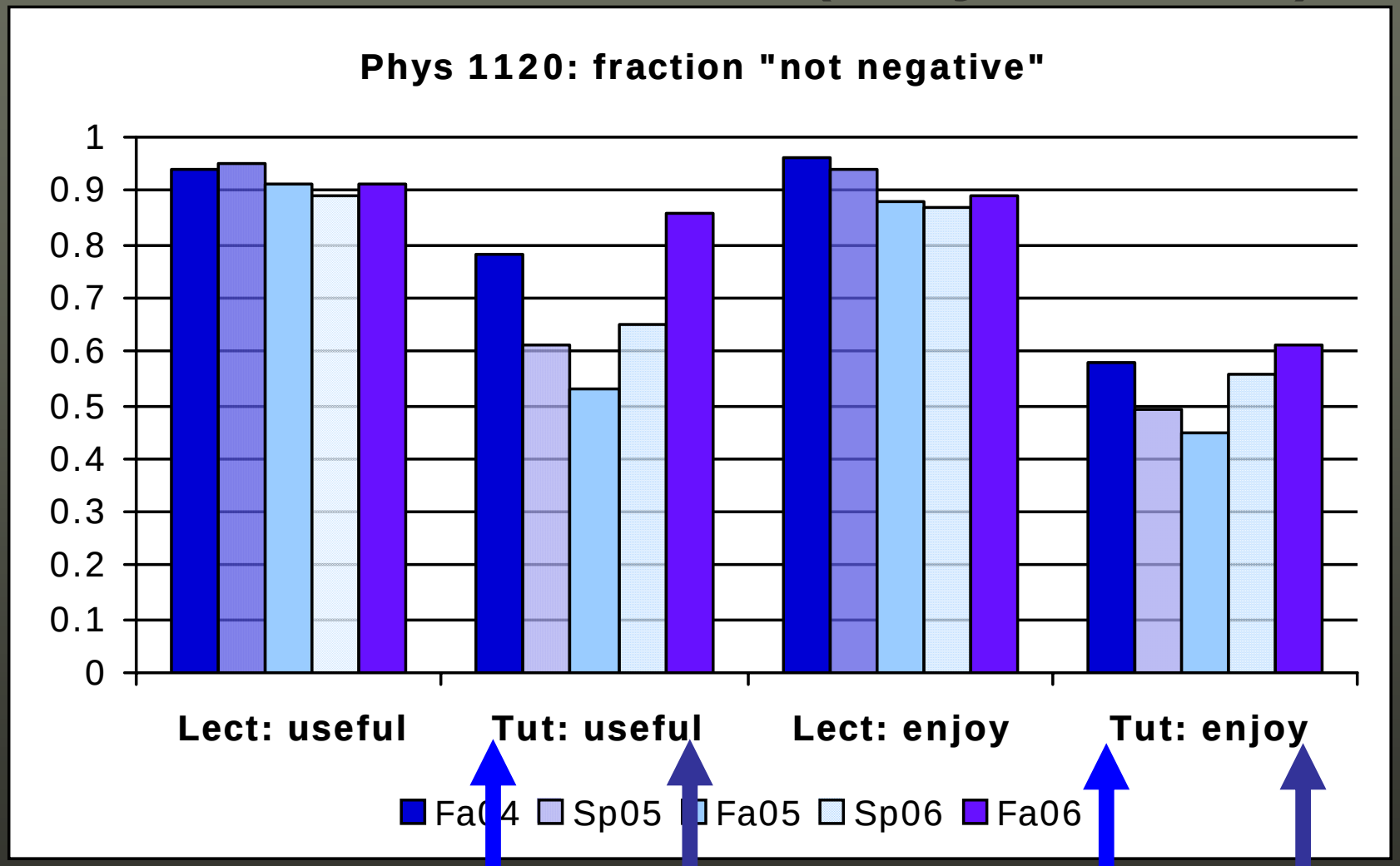
Phys 1110 Fa03 - PER instructor



Low learning gain <---------> high learning gain

Adams et al. (2006) *Physical Review*, ST:PER, 010101
Perkins et al (to appear). Proceedings of PERC

Affect: Tutorials (Phys 1120)



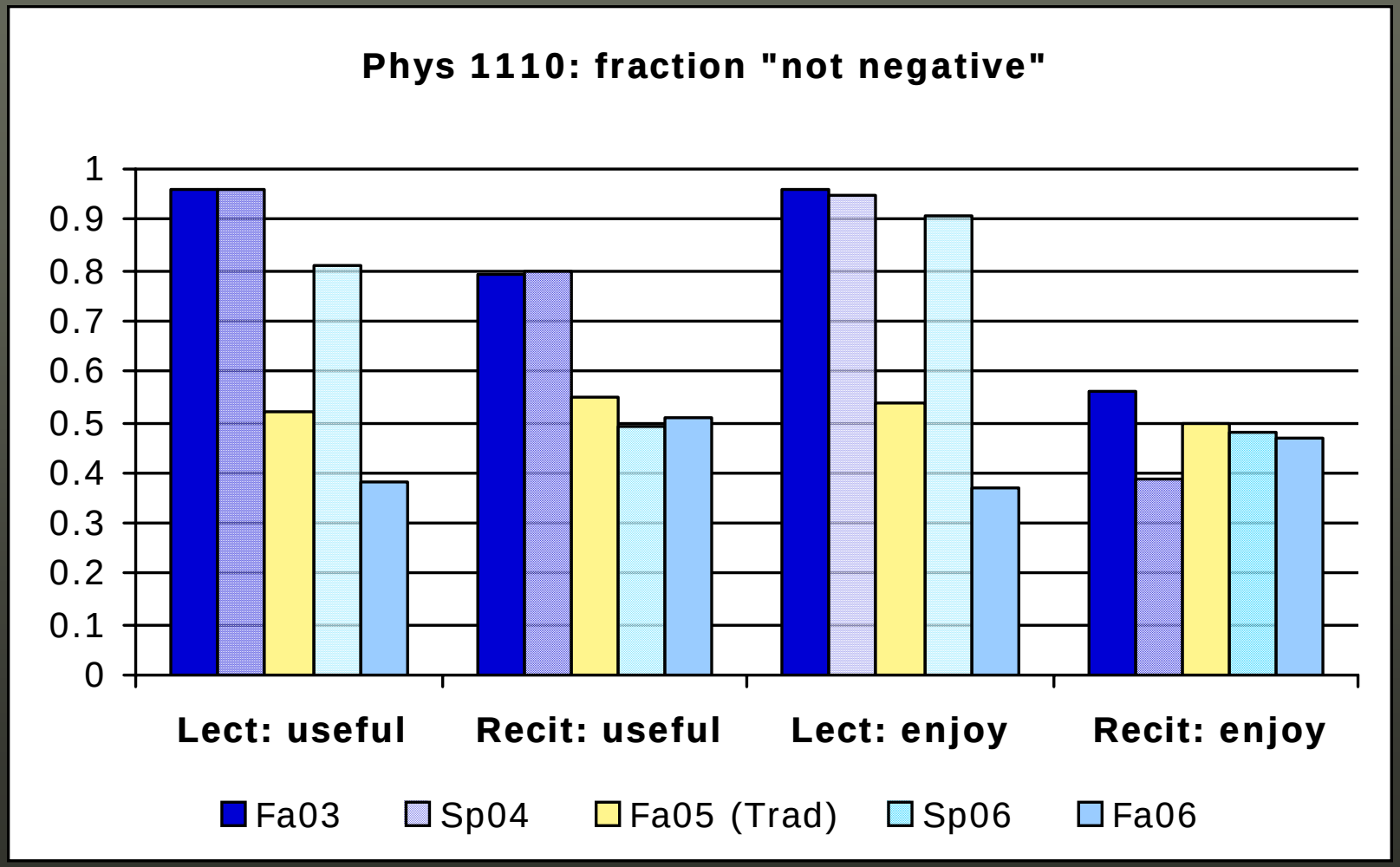
Exams 25% “Tutorial-like” questions

Affect: Tutorials (Phys 1120)

The *spinach model* of educational reform?

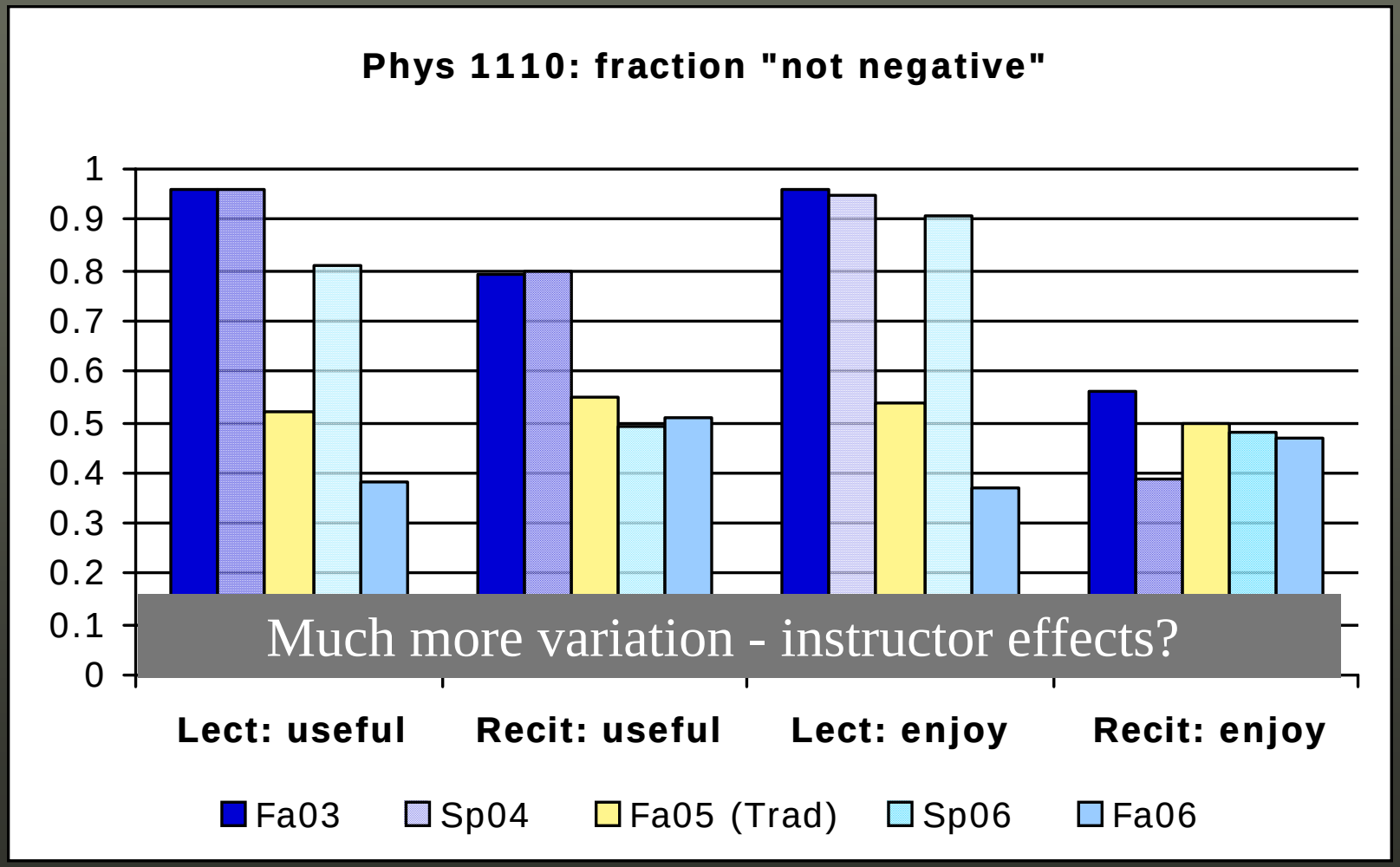
- Students (sometimes) find Tutorial useful
- But more rarely find them enjoyable.

Affect: Tutorials (Phys 1110)



(Missing data for 2 “trad” terms)

Affect: Tutorials (Phys 1110)



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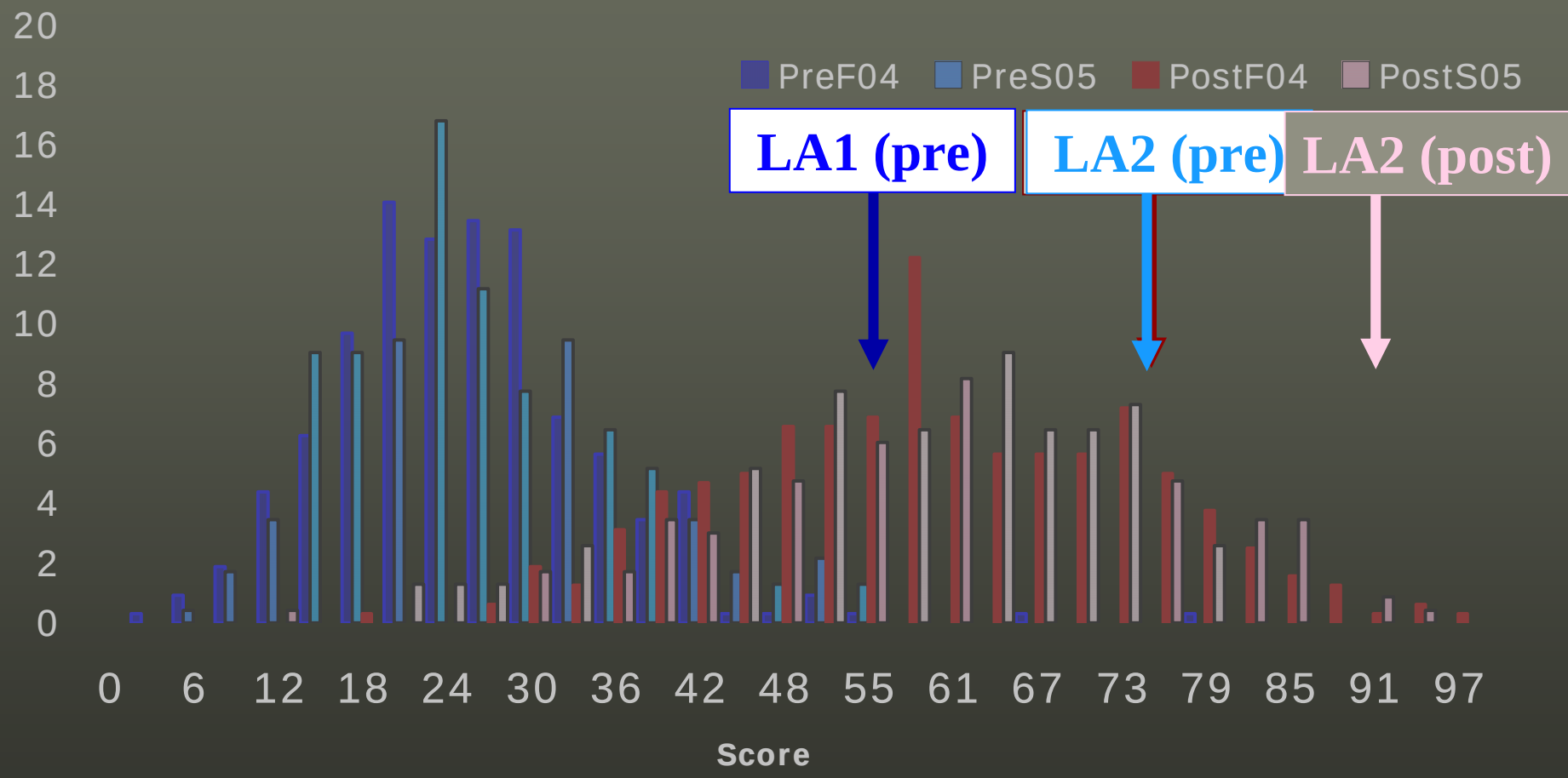
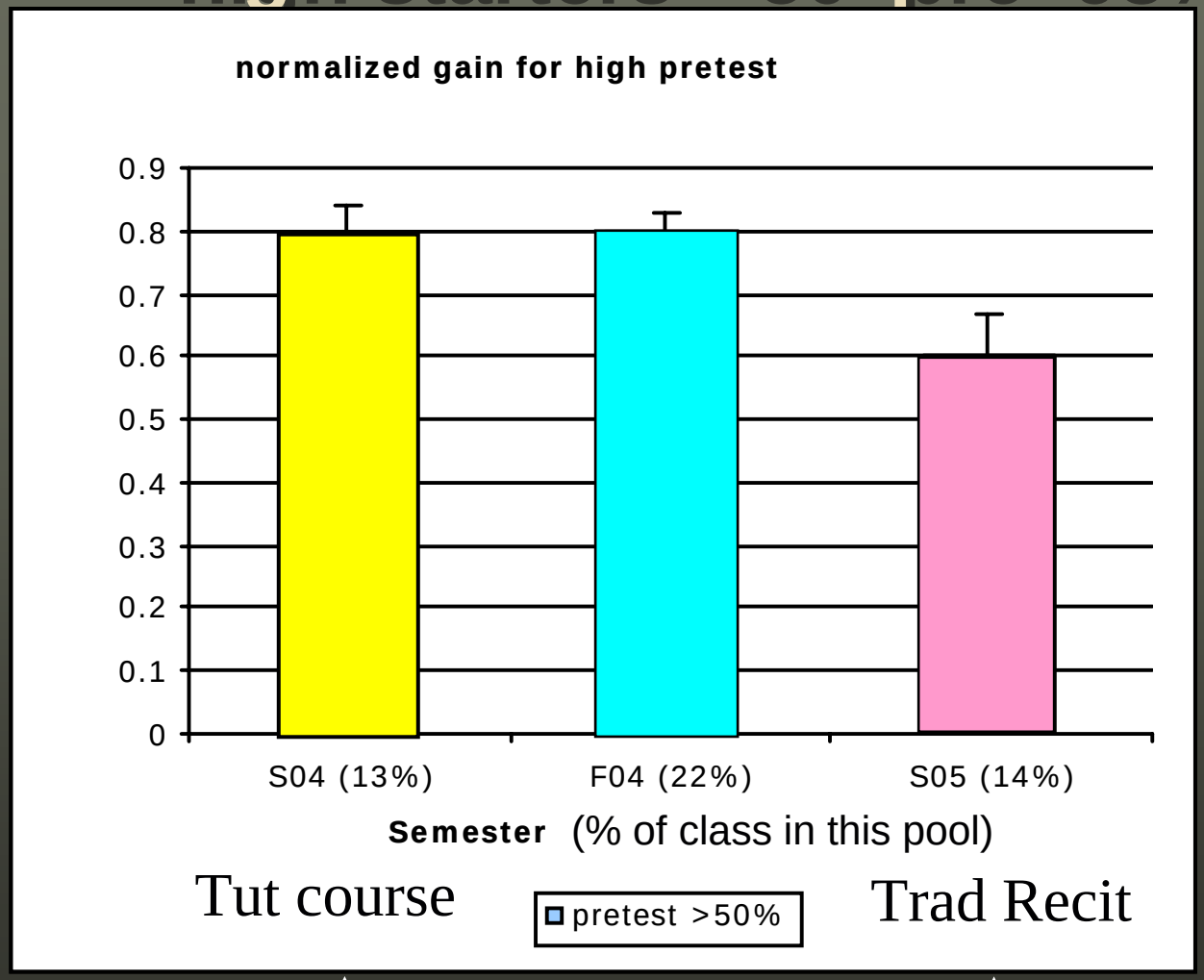
1120 BEMA LA's

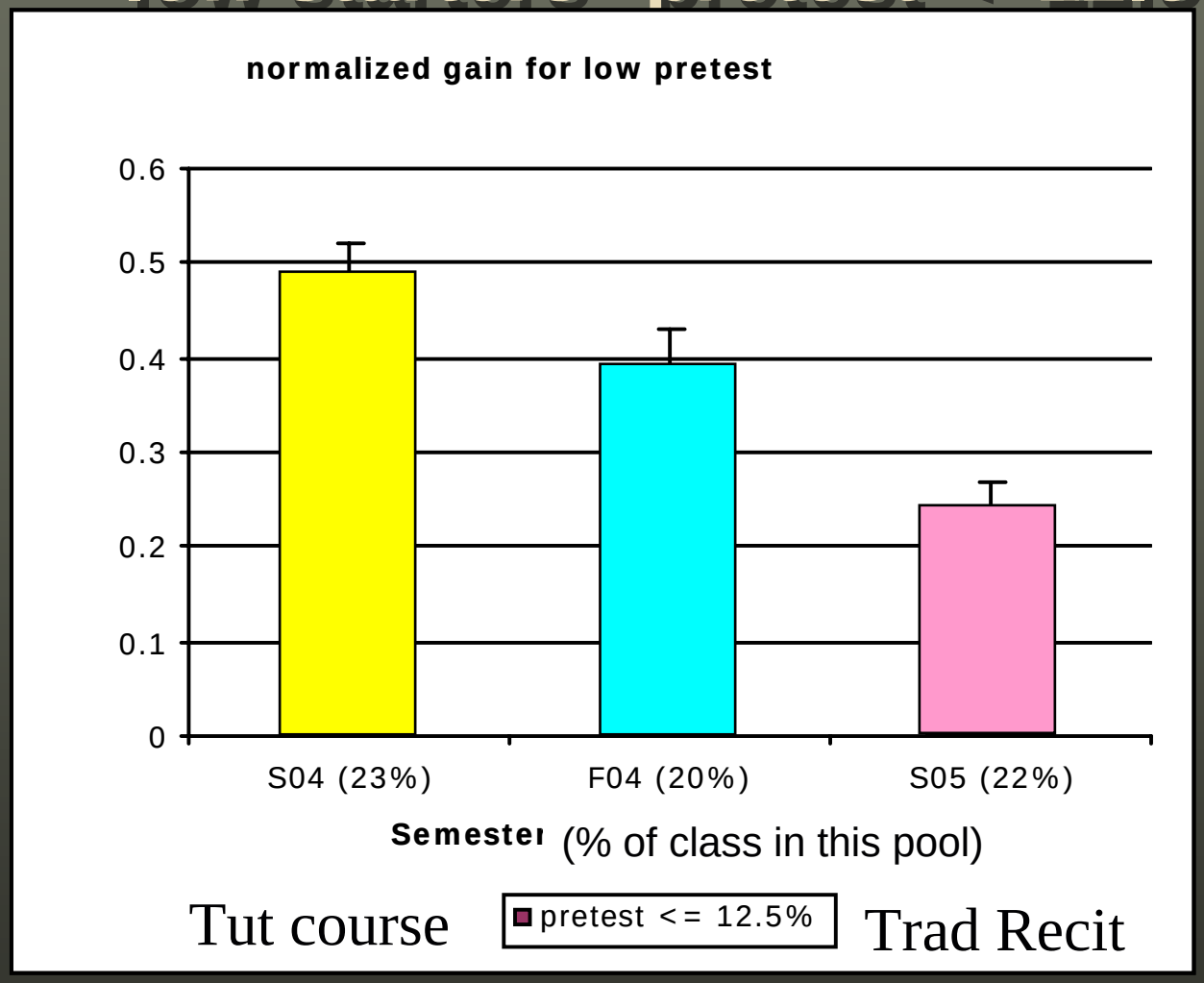


Impact on different pretest populations: "high starters" 50<pre<93%



Course (1) (2) (3)

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



Course (1) (2) (3)