STATE OF THE ART & GETTING STARTED IN PHYSICS EDUCATION RESEARCH

APS- SBF Physics Professor Lecture Series
8 Nov 2016

Instituto de Física
Universidade Federal do Rio de Janeiro

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PER @ CU-Boulder

PHYSICS EDUCATION RESEARCH AT CU BOULDER

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Emily Quinty, Sam Reid
Sara Severance

PER @ CU-Boulder

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Howard Hughes Medical Institute

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Ian Her Many Horses
Jessica Hoy
George Ortiz
Enrique Suarez
Bethany Wilcox
+recent grads (4 PhD)
+ many participating faculty and LAs

Adam Blanford
Adam Light
Akira Miyake
Alice Healy
Anastasia Maines
Andrea Bair
Andrew Martin
Angel Hoekstra
Angela Bielefeldt
Anne Bekoff
Anne Dougherty
Anne Gold
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Anne-Marie Hoskinson
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Ben Van Dusen
Benjamin Zwickel
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Brian Argrow
Brian Couch
Callie Pilzer
Cathy Regan
Chandra Turpen
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Ian Her Many Horses
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Kelly Battin
Kelly Lancaster
Kevin McElhaney
Kim Trenbath
Krista Marshall
Laird Kramer
LaRuth McAfee
Laura Border
Lauren Kost-Smith
Laurie Langdon

Leilani Arthurs
Lindsay Anderson
Lorrie Shepard
Louisa Harris
Maegan Gilmour
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Marie Boyko
Marina Cogan
Marina Kogan
Marina LaGrave
Mike Ross
Miranda Rieter
Nancy Guild
Nathan Canney
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Stephanie Rivale
Stephen Butler
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Steve Pollock
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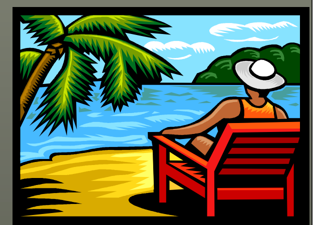
Tyler Schelpat
Ulaff (Benjamin
Uma Swamy
Valerie Otero
Valerie Williams
Victoria Hand
Virginia Ferguson
Wahab Baouchi

Center for STEM Learning
UNIVERSITY OF COLORADO **BOULDER**

physics pedagogy astronomy biology mathematics geology chemistry engineering
Discipline Based Education Research
University of Colorado, Boulder

Why Education?

Individual Empowerment



Societal Empowerment

Workforce / Economic Development

Why PER?

Why PER?

As a subfield of physics like all others (Basic)

- Studying cognitive processes
- Ontological conceptions of physics
- Analogy use
- Theory

In Service to Physics & Education (Applied)

- Curricular development
- Transforming courses
- Addressing challenges:
  - K12 teachers
  - 1M more STEM Majors
  - Faculty development

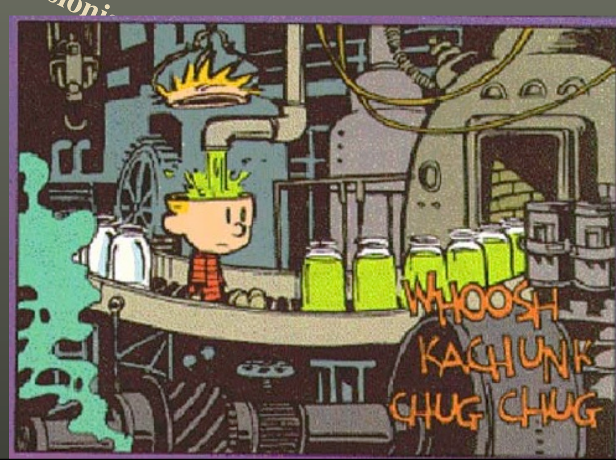
A Third Space? Transforming Physics

- Changing what counts as physics content, process
- Who does physics…
- ???

Trad'l Model of Education

transmission

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



Built in to our classes?

1980's establish PER in US

diSessa, A. (1980). Momentum flow as an alternative perspective in elementary mechanics. ***American Journal of Physics***, 48, 365-369.

Trowbridge, D. E., McDermott, L. C. (1980). Investigation of student understanding of the concept of velocity in one dimension. ***American Journal of Physics***, 48, 1020-1028.

Champagne, A. B., Klopfer, L. E. , Anderson, J. (1980). Factors influencing the learning of classical mechanics. ***American Journal of Physics***, 48, 1074-1079.

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. ***European Journal of Science Education,*** 1(2), 205-221.

Larkin, J., et al. (1980). Expert and novice performance in solving physics problems. ***Science***, 208(4450), 1335-1342.

McCloskey, et al. (1980). Curvilinear motion in the absence of external forces: Naive beliefs about the motion of objects. ***Science***, 210(5), 1139-1141.

Chi, M.T. et al. (1981). Categorization and representation of physics problems by experts and novices. ***Cognitive Science***, 5, 121 - 152.

Clement, J. (1982). Student preconceptions in introductory mechanics. ***American Journal of Physics***, 50, 66.

Hewson, P.W. (1981). A conceptual change approach to learning science. ***European Journal of Science Education***, 3(4), 383-396.

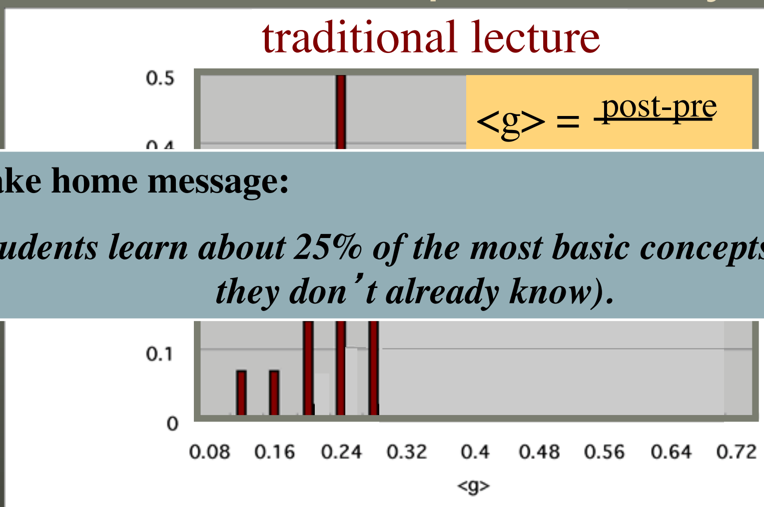
Posner, G., et al. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. ***Science Education***, 66(2), 211-227.

A possible tipping point

- **Force Concept Inventory**
- Multiple choice survey (pre/post)
- A necessary (likely not sufficient) measure of understanding:
  - Most basic concepts
  - Research based (with distracters)
  - Good to demonstrate lack of learning

* Halloun and Hestenes, AJP, (1985);
Hestenes, Wells, Swackhamer, Physics Teacher 20, (92) 141

Force Concept Inventory



Take home message:

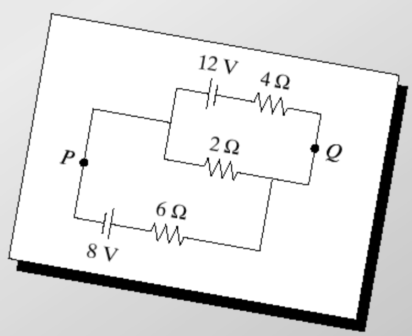
Students learn about 25% of the most basic concepts (that they don't already know).

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

Calculate:

(*a*) current in 2-Ω resistor

(*b*) …

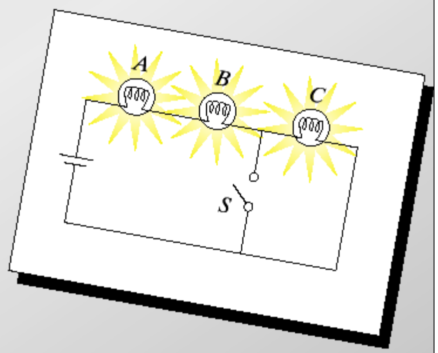


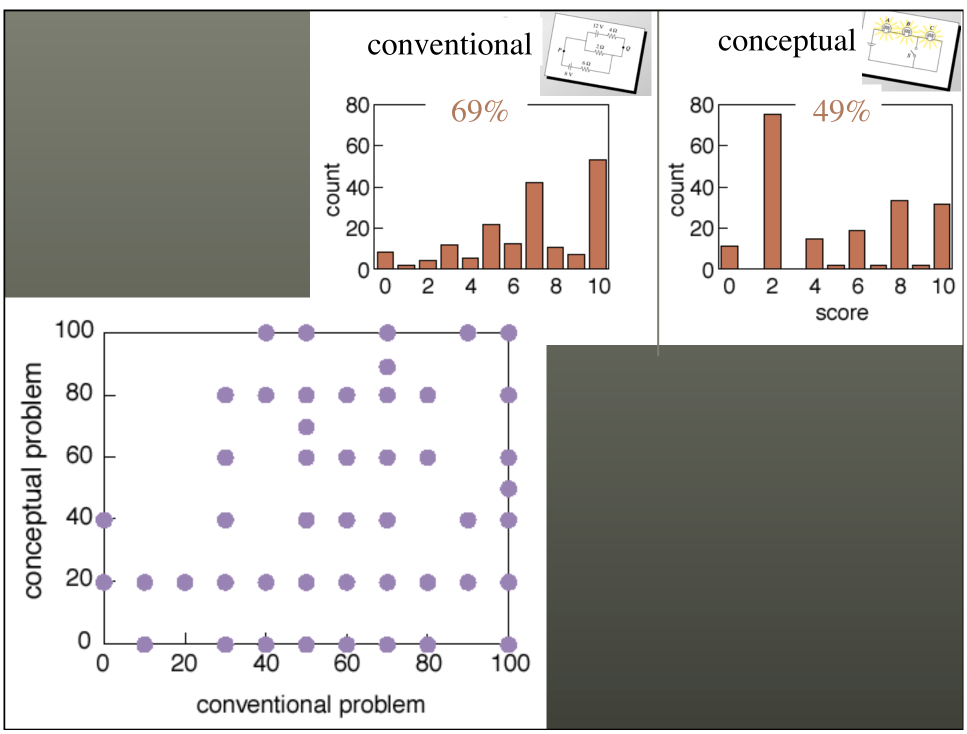
Mazur (1997; 2004)

When *S* is closed, what happens to:

(*a*) intensities of A and B?

(*b*) …





PER Theoretic Background

transmissionist

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

constructivist

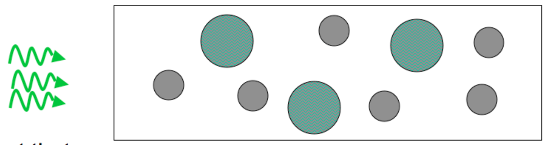
Individual ↔ Active construction — Content

Prior knowledge

actively engaging students is important

Personal Response System

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



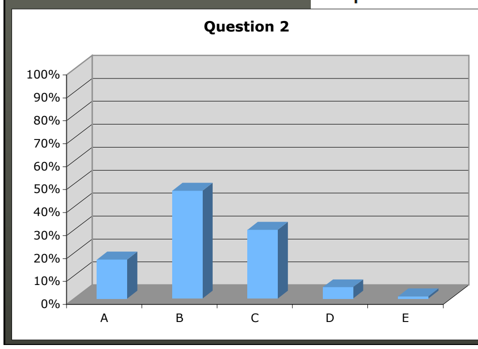
Expect that on average

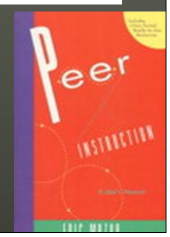
s will come out right hand end of tube

ut right

r as go in

ne out.

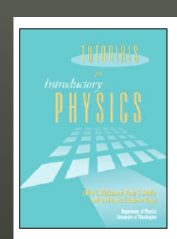




Tutorials in Introductory Physics

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

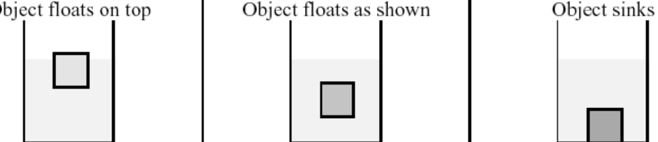
Hands-on, Inquiry-based, Guided, Research-based

Assignment 11M: Name ________________

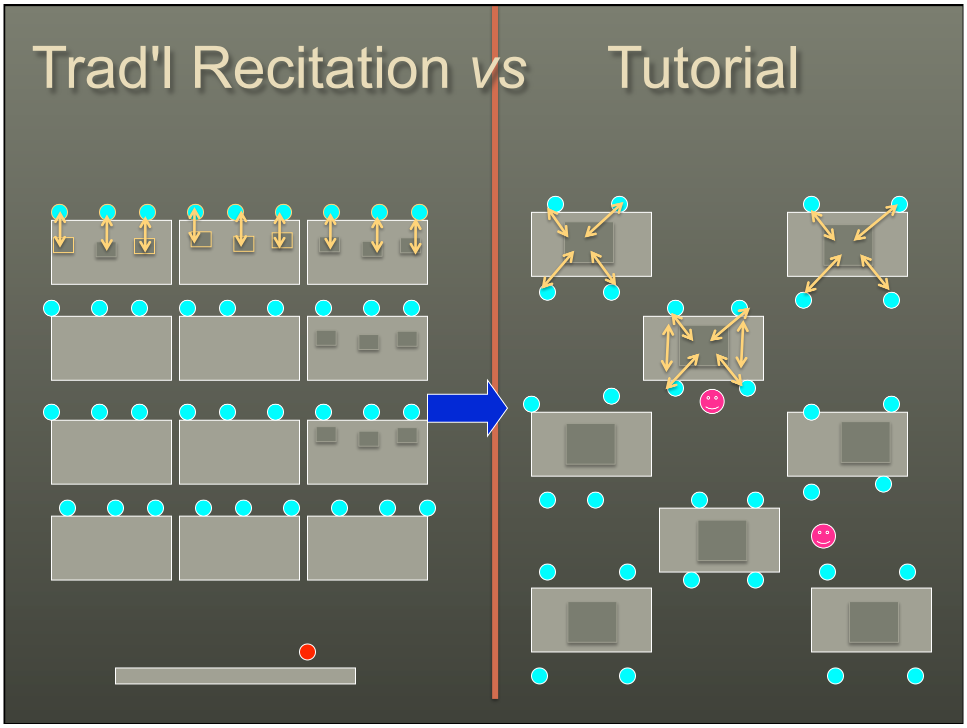
Buoyancy Tutorial section________________

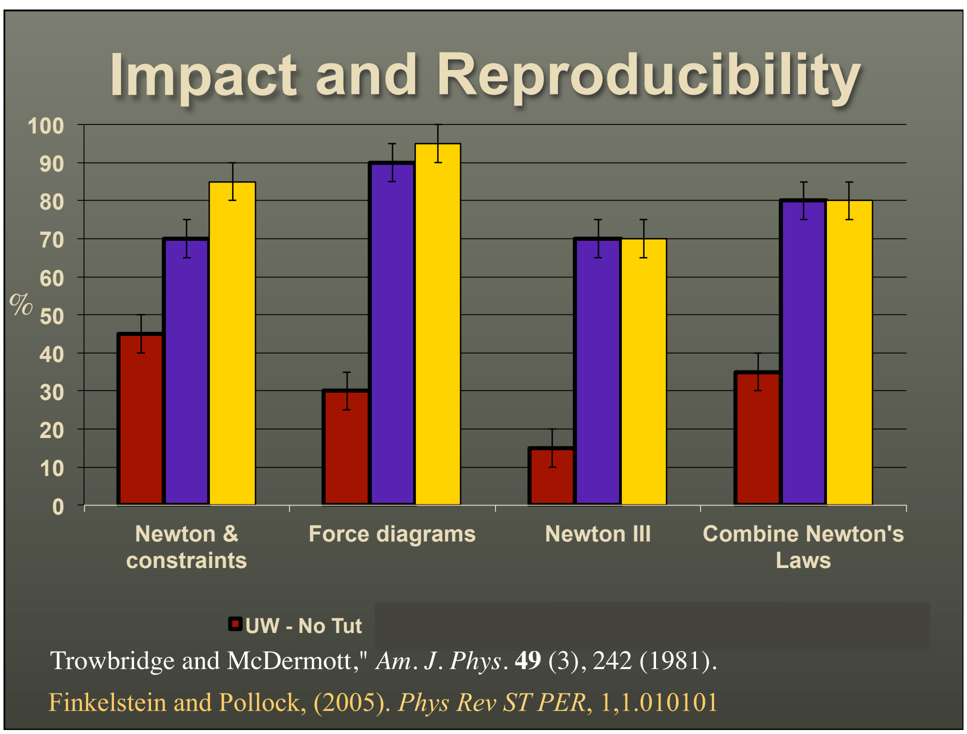
1. Three objects are at rest in three beakers of water as shown.
   a. Compare the mass, volume, and density of the objects to the mass, volume, and density of the displaced water. Explain your reasoning in each case.

Object floats on top	Object floats as shown	Object sinks



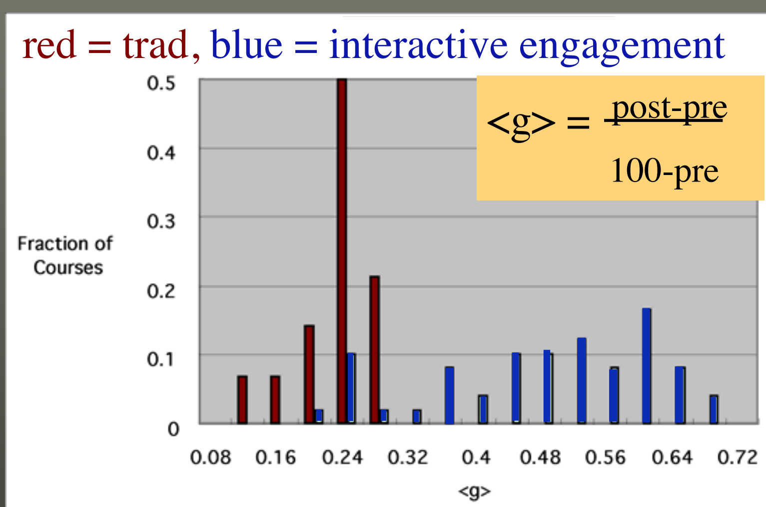
Is m_{object} (>, <, =) $m_{displaced\ water}$? Explain	Is m_{object} (>, <, =) $m_{displaced\ water}$? Explain	Is m_{object} (>, <, =) $m_{displaced\ water}$? Explain


Trad'l Recitation vs
Tutorial


Impact and Reproducibility
100
90
80
70
60
%
50
40
30
20
10
0
Newton & constraints
Force diagrams
Newton III
Combine Newton's Laws
UW - No Tut
Trowbridge and McDermott," Am. J. Phys. 49 (3), 242 (1981).
Finkelstein and Pollock, (2005). Phys Rev ST PER, 1,1.010101

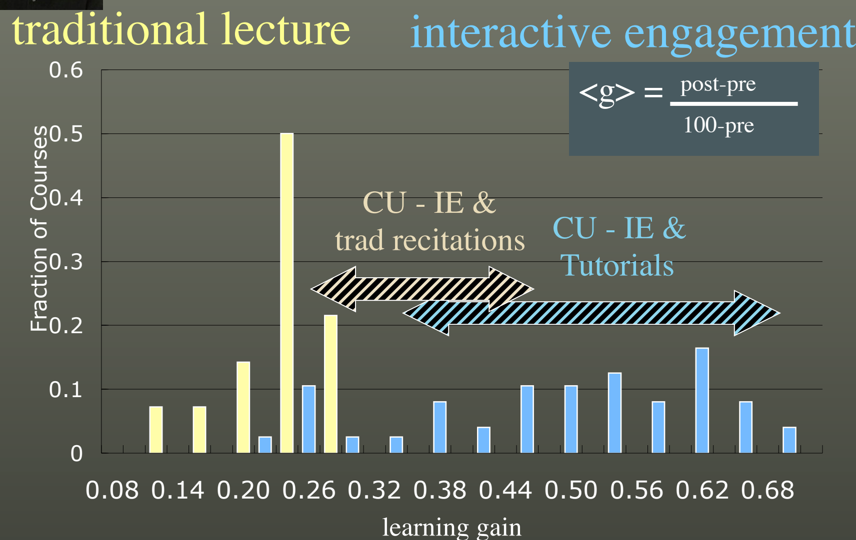
by actively engaging students…

Back to the FCI



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

Engagement in Learning



Hake 1998, AJP (original data)
Pollock & Finkelstein, Physical Review, 4, 010101 (2008).

"If the experiments analyzed here had been conducted as randomized controlled trials of medical interventions, they may have been stopped for benefit" -Freeman, PNAS 2014

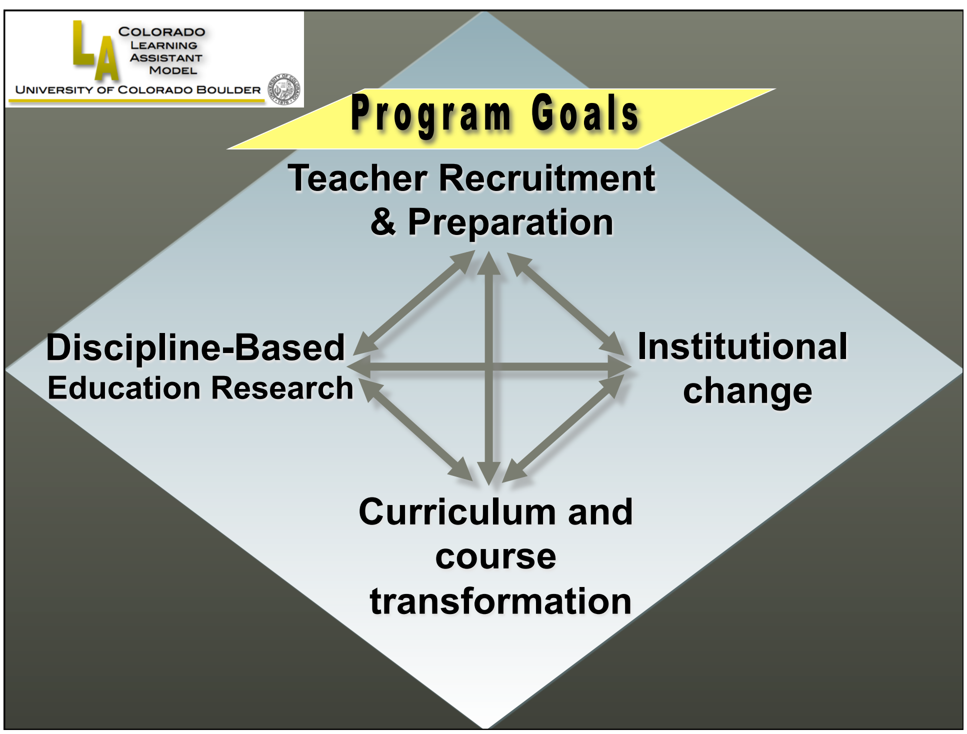
Active learning increases student performance in science, engineering, and mathematics

Scott Freeman[a,1], Sarah L. Eddy[a], Miles McDonough[a], Michelle K. Smith[b], Nnadozie Okoroafor[a], Hannah Jordt[a], and Mary Pat Wenderoth[a]

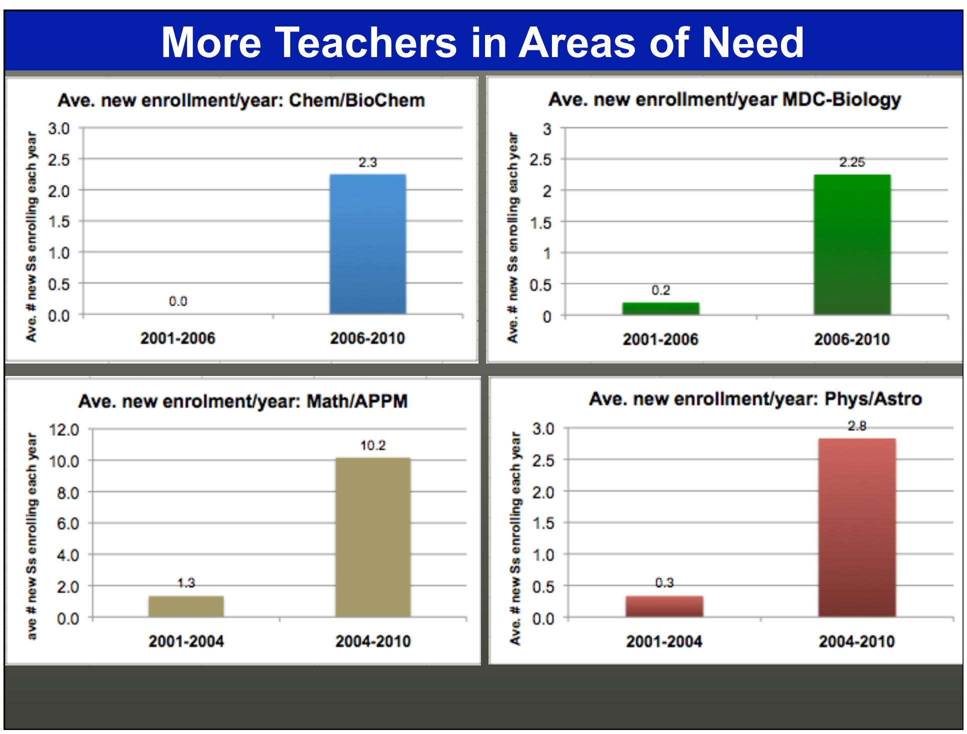
COLORADO LEARNING ASSISTANT MODEL
UNIVERSITY OF COLORADO BOULDER

Valerie Otero (lead)
Steven Pollock (phys)

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




Courses Transformed using Learning Assistants (LAs)
These LAs make up the pool from which we recruit (and prepare) new K-12 teachers


More Teachers in Areas of Need
Ave. new enrollment/year: Chem/BioChem
Ave. # new Ss enrolling each year
0.0
2.3
2001-2006
2006-2010
Ave. new enrollment/year MDC-Biology
Ave. # new Ss enrolling each year
0.2
2.25
2001-2006
2006-2010
Ave. new enrolment/year: Math/APPM
ave # new Ss enrolling each year
1.3
10.2
2001-2004
2004-2010
Ave. new enrollment/year: Phys/Astro
Ave. # new Ss enrolling each year
0.3
2.8
2001-2004
2004-2010

PER Theoretic Background

transmissionist

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

Enhanced constructivist

Individual ↔ Active construction ↔ Content

- Prior knowledge
- Student background
- Attitudes and Beliefs
- Affect

Attitudes & Beliefs:

Edward F. Redish, et al, Am. J. Phys. 66, 212-224 (1998).

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

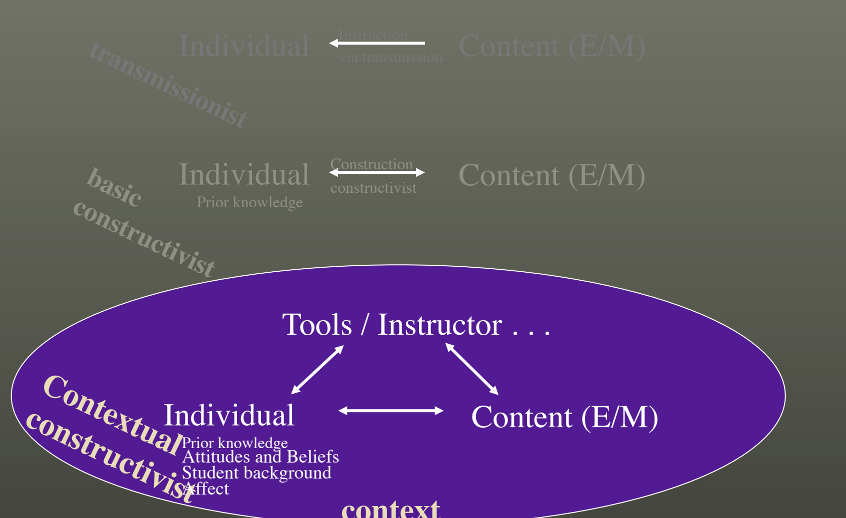
CLASS categories

	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%)	

U.S. phase transition

- APS Statement 99:2 (1999): endorsing PER in physics
- PERLOC (2006): establish a governance board
- Conferences in PER
  - PERC (since 1997)
  - Gordon Conferences in PER (2000)
  - Frontiers and Foundations in PER (2005)
  - Fermi Summer School (2003)
- Peer Reviewed Venues
  - **Am Jour. Of Physics -** PER Supplement (1990's)
  - **PERC Proceedings** (of the PER Conference) (2000)
  - **Physical Review:** ST Physics Education Research (2005)

PER Theoretic Background



Finkelstein, N. (2005) Context in the Context of Physics Education, *IJSE*
Finkelstein, N. (2005-2010). NSF CAREER Grant: REC# 0448176

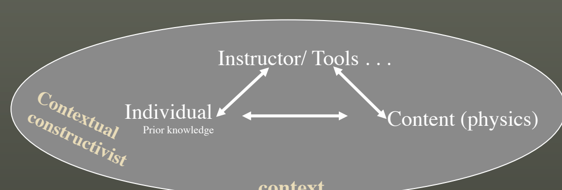
a contextual perspective

people's knowing & cognition in physics is situated within social, cultural and historical contexts

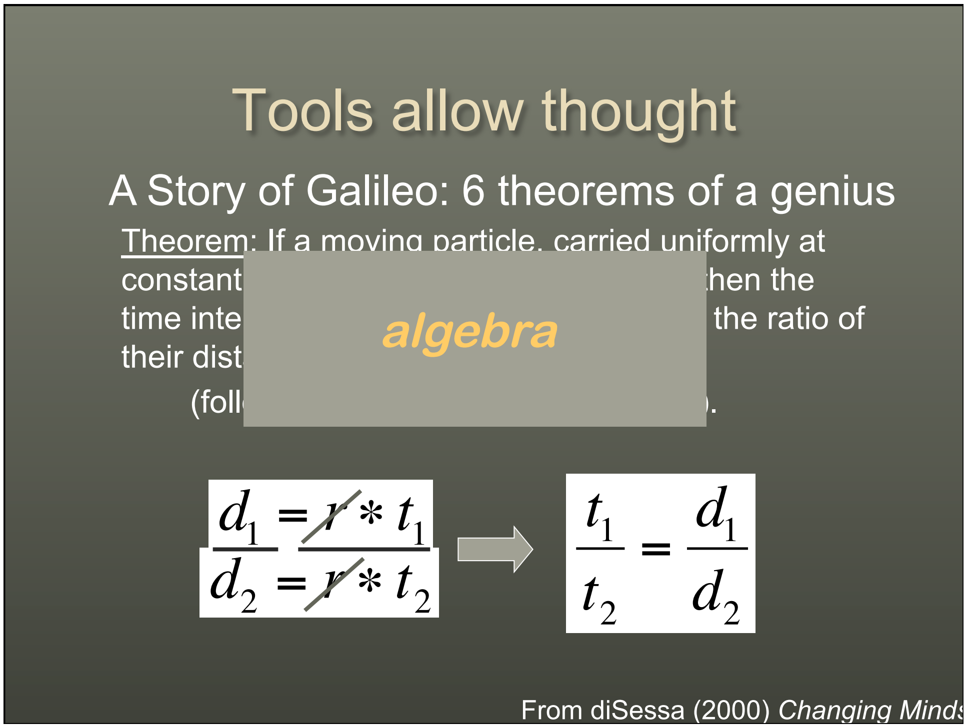
Theoretical Framework

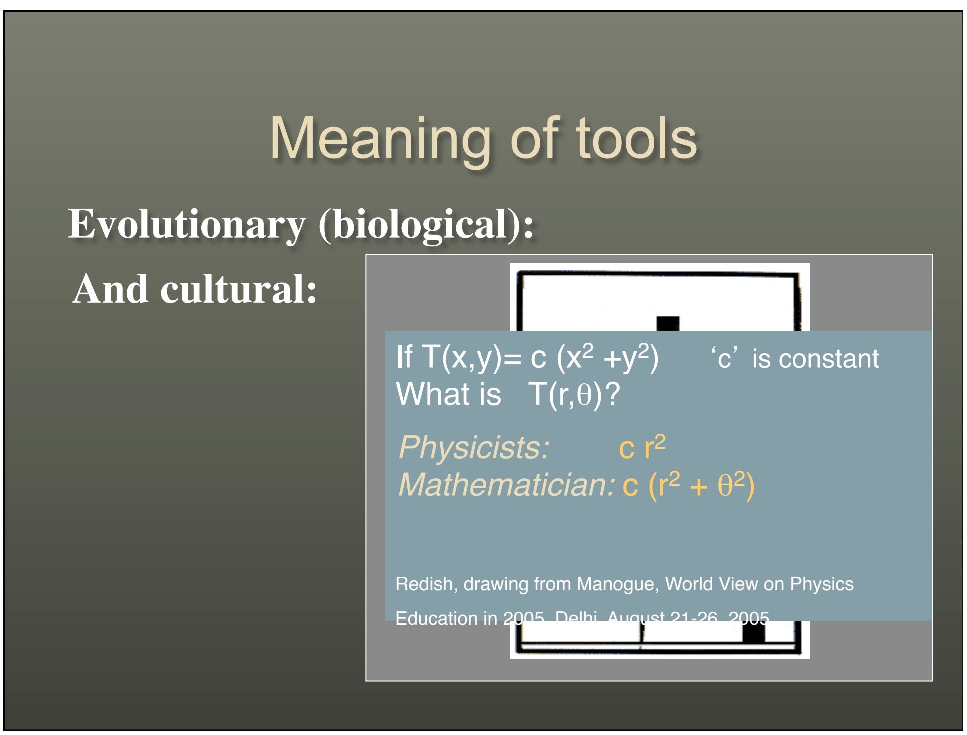
Contextual Constructivism

i. tools mediate our understanding / cognitive processes
ii. context shapes how we might use these tools



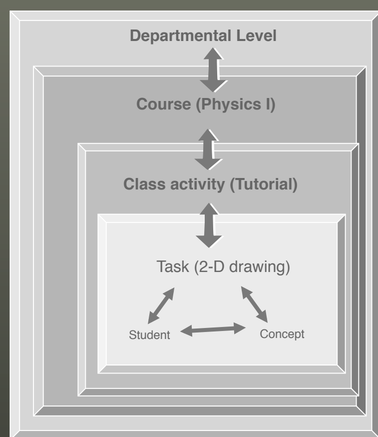
Finkelstein (2005), adapted from Cole, M. (1996), Cultural Psychology


Tools allow thought
A Story of Galileo: 6 theorems of a genius
Theorem: If a moving particle, carried uniformly at
constant
hen the
time inte
the ratio of
their dist
(foll
algebra
$d_1 = r * t_1$
$d_2 = r * t_2$
$\frac{t_1}{t_2} = \frac{d_1}{d_2}$
From diSessa (2000) Changing Minds


Meaning of tools
Evolutionary (biological):
And cultural:
If T(x,y)= c (x^2 +y^2)   'c' is constant
What is T(r,θ)?
Physicists: c r^2
Mathematician: c (r^2 + θ^2)
Redish, drawing from Manogue, World View on Physics
Education in 2005, Delhi, August 21-26, 2005

Embedded Context(s)

Frames of Context



Finkelstein, N. (2005). *Int. J. Science Education.*

A broad perspective

a. Individ'l
b. Course
c. Depart'l

C. Baily and N. Finkelstein, *Phys. Rev. ST Physics Ed. Research* 6, 020113 (2010).
W.K. Adams, et al. *Physical Review ST: Physics Education Research*, 2, 1, 010101 (2006).
K.K. Perkins et al. *Proceedings of the 2005 PER Conference (PERC)* AIP Press 818 (2006).
N.D. Finkelstein, *J. of Online Learn & Teaching*, 2, 109 (2006).
K.K. Perkins, et al. *Physics Teacher* 44(1) 18 (2006)
N.D. Finkelstein, et al. *Physical Review, ST: Physics Education Research*, 1, 010103 (2005).
C. Turpen and N.D. Finkelstein, *Phys. Rev. ST Physics Ed. Research* 6, 020123 (2010).
S. Pollock and N. Finkelstein, *Phys. Rev. ST Physics Ed. Research* 4, 010110 (2008)
N.D. Finkelstein & S.J. Pollock, *Physical Review, ST: PER*, 1, 010101 (2005)

Foregrounding Context in PER

Themes / Frames of Context	i. Tools	ii. Practices	iii. Norms
a. Individ'l	Representation Analogy PhET	Tch to Lrn Physics Labs Talking Physics	Class (beliefs) Interp in QM
b. Course	Sims in Class Clickers in Class Using Reps & Analogy	Course Redesign Clicker Use Tutorials	Tutorial Adaptation Tchng Interpret. Gender intervention
c. Depart'l	Faculty use of PER Frameworks of change	TA, PD, Fac Dvmt Community Partnr	Dept'l norms Partnership in Phys Inclusion

NSF 0448176, CAREER: 2005-2011.

Instructional implications:

actively engaging is important

what people know affects what they learn

tools & contexts shape what students learn

Current Directions

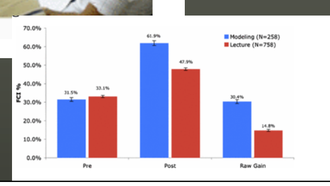
- Reconsidering educational environments
- Beyond conceptual mastery:
  - lab skills
  - identity / belonging
  - faculty practices / engagement
- Underpinning neural / cognitive processes
- Systemic factors

Considering Environments

Toward equity through participation in Modeling Instruction in introductory university physics

Eric Brewe, Vashti Sawtelle, Laird H. Kramer, George E. O'Brien, Idaykis Rodriguez, and Priscilla Pamelá
Phys. Rev. ST Phys. Educ. Res. **6**, 010106 – Published 20 May 2010

(a) (b) (c)



Faculty Roles in Classroom

YELLOW:
- Rarely (12% of the time) left the stage.
- Rarely (19% of the time) answered student questions
- Rarely (8% of the time) discussed with students
- Rarely (17% of the time) heard student explanations
- When heard student ex., heard from at least 2 students on average

Low collab. ←→ High collab.

GREEN:
- Rarely (11% of the time) left the stage.
- Occasionally (25% of the time) answered student questions
- Never discussed w/ students
- Always heard student explanations, Usually heard only one correct student explanation
- Usually quick to reveal correctness of student explanation

RED:
- Often (69% of the time) left the stage
- Often (63% of the time) answered student questions, Often (84% of the time) discussed with students
- Usually heard student explanations, and usually heard from multiple students
- Usually withheld expert evaluation of answer correctness until consensus developed

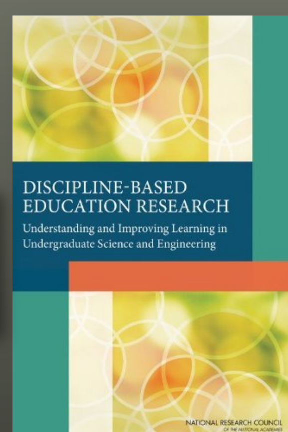
Turpen 2010,2012

New Directions in Physics Education Research

Lectures → Labs

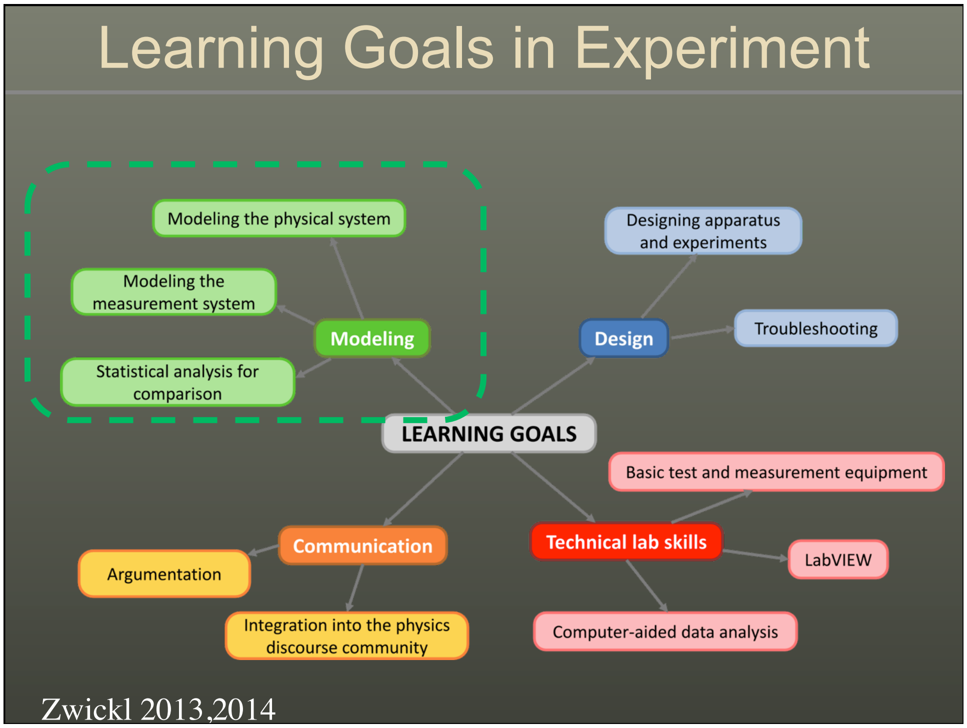
Introductory → Upper-division

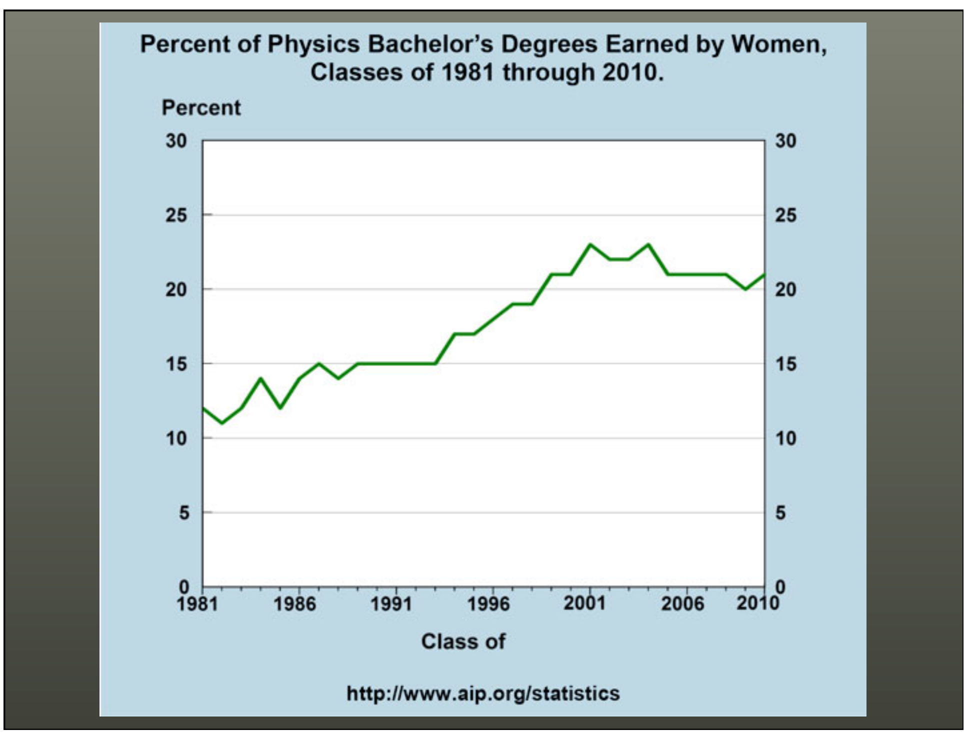
"Across the disciplines in this study, the role of the laboratory class is poorly understood."



NRC Report on Discipline-Based Education Research (2012)

Lewendowski & collaborators


Learning Goals in Experiment
Modeling the physical system
Modeling the measurement system
Modeling
Statistical analysis for comparison
Designing apparatus and experiments
Design
Troubleshooting
LEARNING GOALS
Basic test and measurement equipment
Communication
Technical lab skills
LabVIEW
Argumentation
Integration into the physics discourse community
Computer-aided data analysis
Zwickl 2013,2014

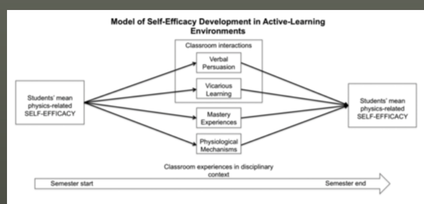

Percent of Physics Bachelor's Degrees Earned by Women, Classes of 1981 through 2010.
Percent
30
25
20
15
10
5
0
1981
1986
1991
1996
2001
2006
2010
Class of
http://www.aip.org/statistics

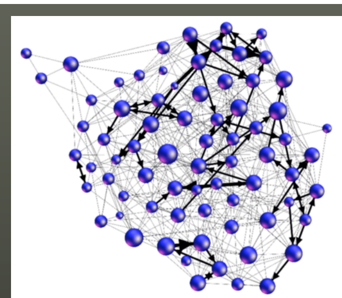
Beyond Concepts

Beyond performance metrics: Examining a decrease in students' physics self-efficacy through a social networks lens

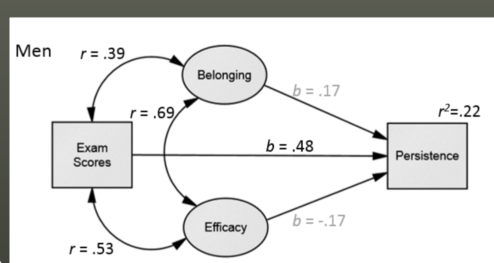
Remy Dou, Eric Brewe, Justyna P. Zwolak, Geoff Potvin, Eric A. Williams, and Laird H. Kramer

Phys. Rev. Phys. Educ. Res. **12**, 020124 – Published 9 August 2016



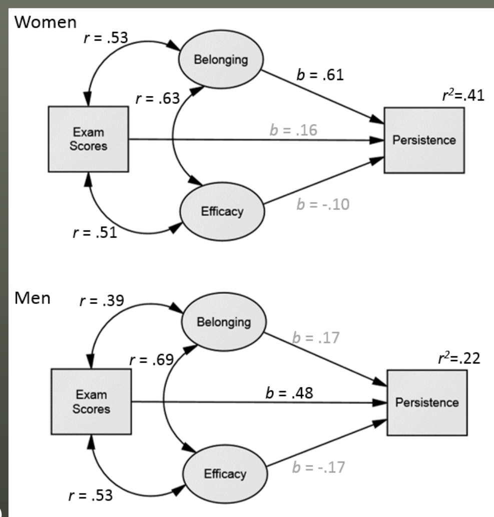


Survey of Physics 1



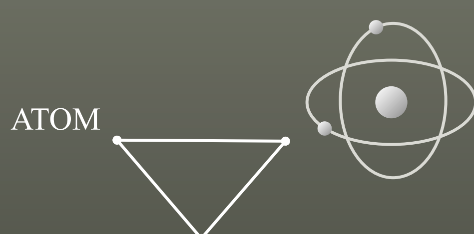
Lewis (in review)

Survey of Physics 1



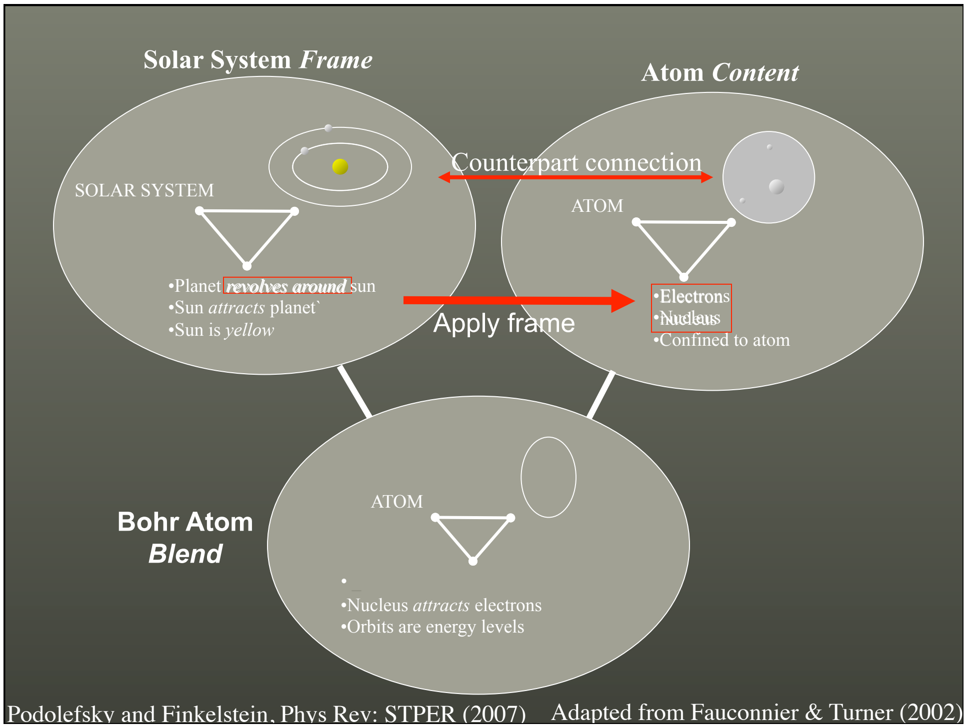
Lewis (in review)

How do we connect representations, objects, schema?



•Electron *revolves around* nucleus
•Nucleus *attracts* electron

blending



Future Directions?

It's tough to make predictions, especially about the future

- Yogi Berra

Future Directions?

- Cross DBER work
  - Physics for biologists (Maryland)
  - Computational thinking (MSU)
- Broader questions in physics:
  - identity
  - informal learning
  - inclusion (bridging theory / practice)
- Institutional change

Interdisciplinary Work

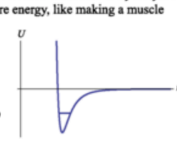
Students' reasoning about "high-energy bonds" and ATP: A vision of interdisciplinary education

Benjamin W. Dreyfus, Vashti Sawtelle, Chandra Turpen, Julia Gouvea, and Edward F. Redish
Phys. Rev. ST Phys. Educ. Res. **10**, 010115 – Published 12 May 2014

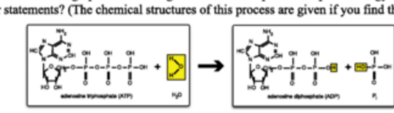
Two students discussing the process of ATP hydrolysis ($ATP + H_2O \rightarrow ADP + P_i$) make the following comments:

Justin: "The O-P bond in ATP is called a 'high-energy bond' because the energy *released* when ATP is hydrolyzed is large. That released energy can be used to do useful things in the body that require energy, like making a muscle contract."

Kim: "I thought chemical bonds like the O-P bond in ATP could be modeled by a potential energy curve like this (she draws the picture at the right), where r is the distance between the O and the P. If that's the case, then breaking the O-P bond in ATP would require me to input energy. I might not have to input much energy to break it, if that O-P happens to be a weak bond, but shouldn't I have to input at least *some* energy?"



How did Kim infer from the PE graph that breaking the O-P bond requires an input of energy? Who's right? Or can you reconcile their statements? (The chemical structures of this process are given if you find that useful.)



Note: This is an essay question. Your answer will be judged not solely on its correctness, but for its depth, coherence, and clarity.

Cross Disciplinary Skills

Understanding Student Computational Thinking with Computational Modeling

John M. Aiken*, Marcos D. Caballero†, Scott S. Douglas**, John B. Burk††, Erin M. Scanlon**, Brian D. Thoms*, Michael F. Schatz**

```
from __future__ import division
from visual import *

craft = sphere(pos = vector(10e7,0,0), colo
Earth = sphere(pos = vector(0,0,0), color =
trail = curve(color = craft.color)

G = 6.67e-11
mcraft = 1500
mEarth = 5.97e24

vcraft = vector(0,2400,0)
pcraft = mcraft*vcraft

t = 0
deltat = 60
tf = 365*24*60*60

while t < tf:

    r = craft.pos-Earth.pos
    rhat = r/mag(r)
    Fgrav = -G*mEarth*mcraft/mag(r)**2*rhat

    pcraft = pcraft+Fgrav*deltat
    craft.pos = craft.pos + pcraft/mcraft*deltat

    trail.append(pos = craft.pos)
    t = t + deltat

```

Initial Conditions

Force Calculation

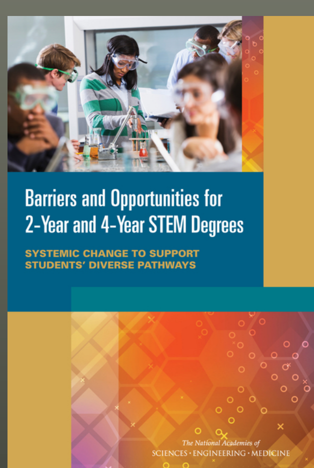
Newton's Second Law

Position Update

Fostering Computational Thinking In Introductory Mechanics

Marcos D. Caballero*,†, Matthew A. Kohlmyer**,‡ and Michael F. Schatz*

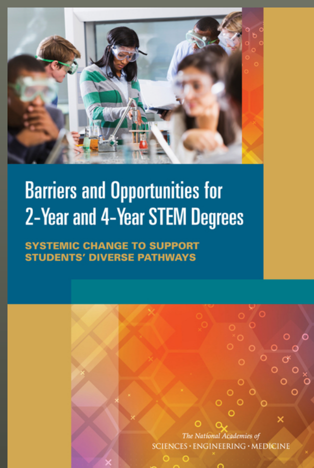
Addressing National Trends



- Shifting Demographics
- Stronger Interest in STEM
- More Complex Pathways
- Rotten Completion Rates

https://www.nap.edu/catalog/21739/barriers-and-opportunities-for-2-year-and-4-year-stem-degrees

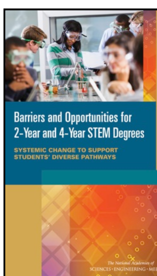
Changing Within



- Shifting Demographics
- Stronger Interest in STEM
- More Complex Pathways
- Rotten Completion Rates

6 Conclusions
9 Recommendations
legislative - classroom

https://www.nap.edu/catalog/21739/barriers-and-opportunities-for-2-year-and-4-year-stem-degrees



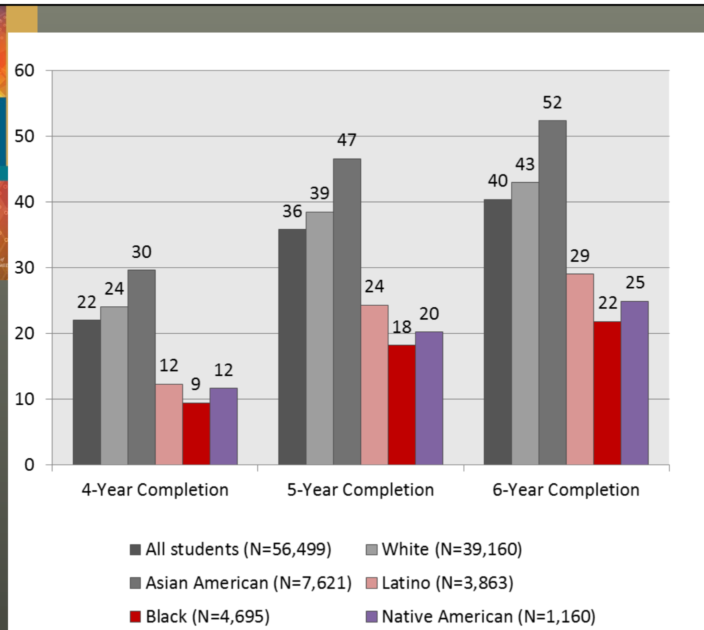
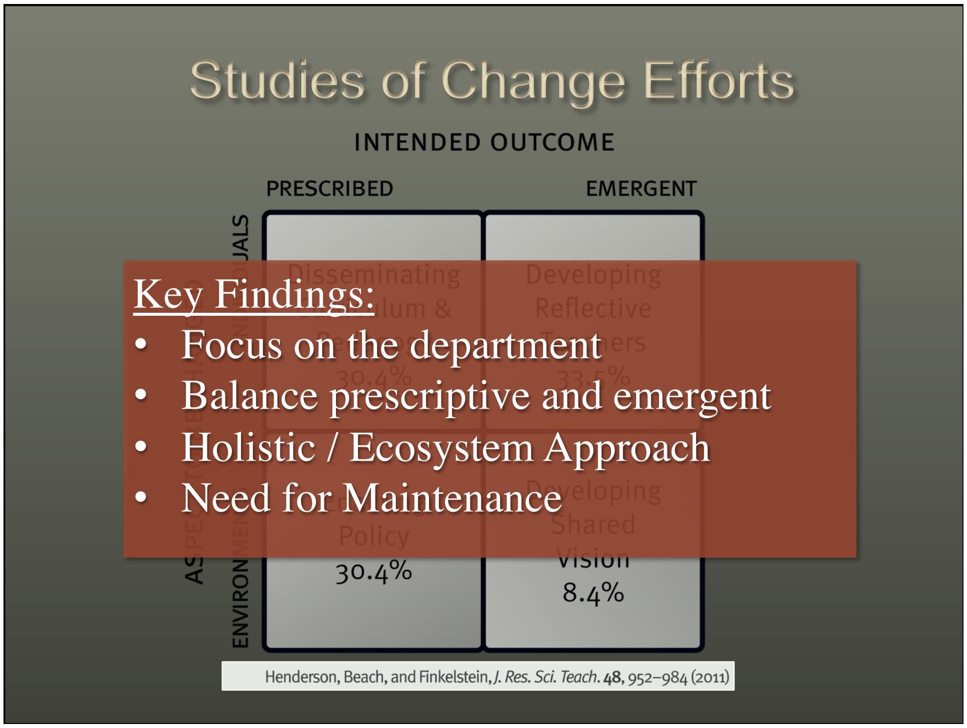
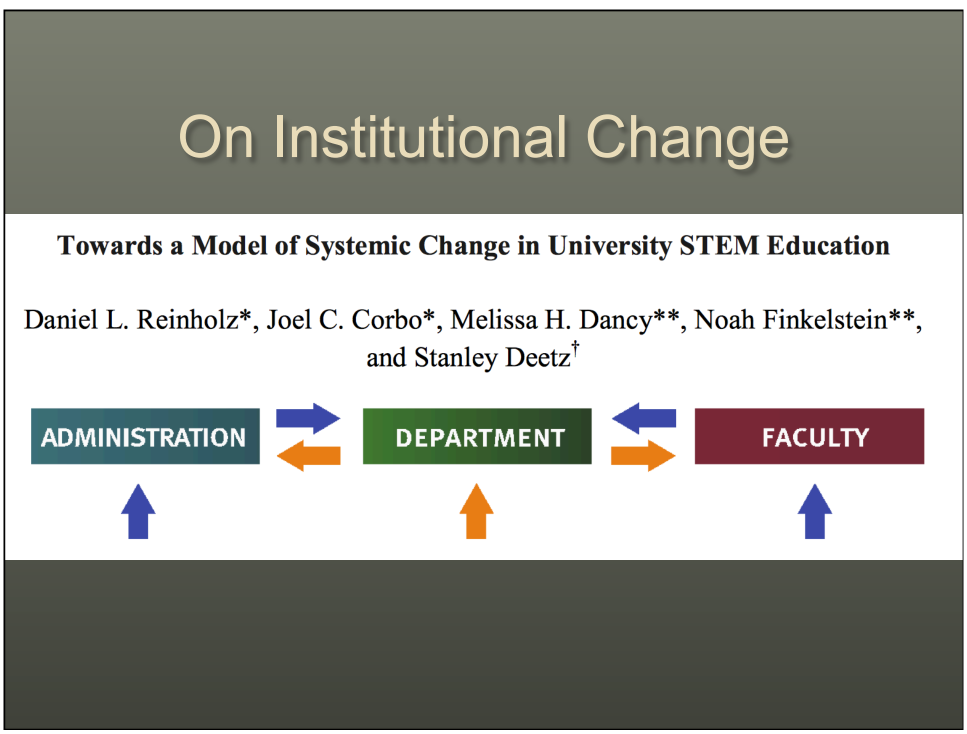
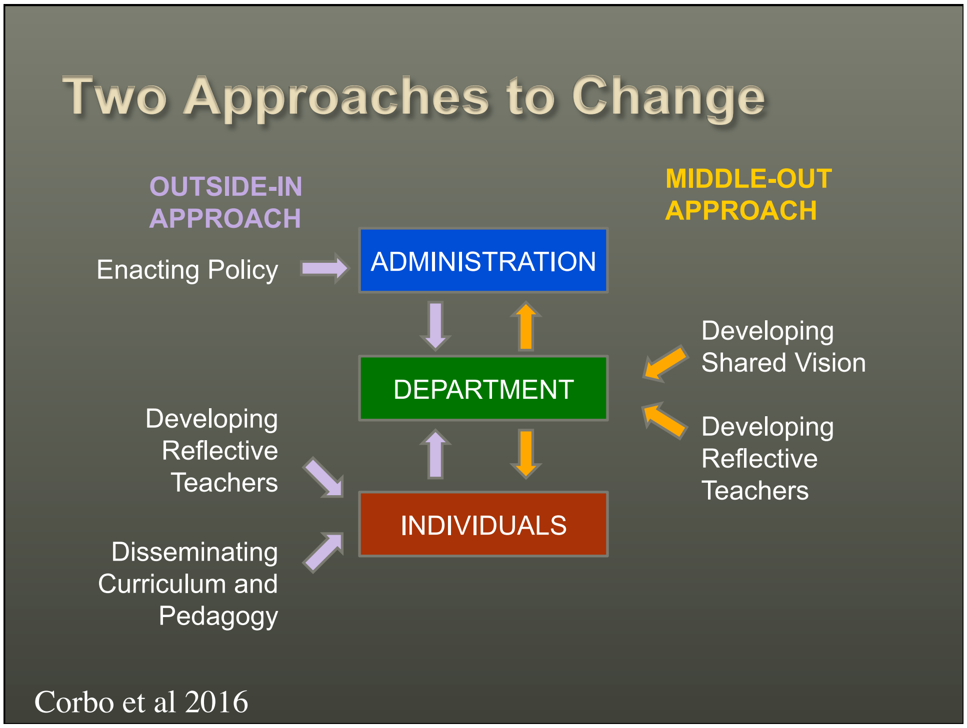


FIGURE 2-5 Cumulative percentage of 2004 STEM aspirants who completed STEM degrees in 4, 5, and 6 years. SOURCE: Eagan et al. (2014, Fig. 7).


Studies of Change Efforts
INTENDED OUTCOME
PRESCRIBED
EMERGENT
30.4%
8.4%
Key Findings:
• Focus on the department
• Balance prescriptive and emergent
• Holistic / Ecosystem Approach
• Need for Maintenance
Henderson, Beach, and Finkelstein, J. Res. Sci. Teach. 48, 952–984 (2011)


On Institutional Change
Towards a Model of Systemic Change in University STEM Education
Daniel L. Reinholz*, Joel C. Corbo*, Melissa H. Dancy**, Noah Finkelstein**, and Stanley Deetz†
ADMINISTRATION
DEPARTMENT
FACULTY



TOWARDS A FRAMEWORK FOR SUPPORTING AND ASSESSING TEACHING QUALITY AT CU-BOULDER

[The University of Colorado Boulder should] enhance efforts to upgrade the prestige, respect and reward structure for excellence in the scholarship of teaching; . . . Develop frameworks in which teaching excellence and dedication are evaluated with a level of scrutiny comparable to how research and creative work is scrutinized.

Recommendation 7
Academic Affairs Persistence Committee
Co-Chairs: M. Grant & J. Cox

Executive Summary

The University of Colorado Boulder requires that "[d]ossiers for comprehensive review, tenure, or promotion must include multiple measures of teaching" (J. Cox, 2007). However, at present we do not have a well-defined framework to guide individuals or departments in the selection and interpretation of such measures, which makes it difficult to assess teaching quality and support faculty growth in their teaching in a systematic way.

This paper outlines a framework for supporting and assessing teaching quality for all instructors across all departments on campus that is grounded in the scholarship of higher education, including the work of Bernstein and colleagues (2002, 2010) and Glassick and colleagues (1997). This framework defines teaching as a scholarly activity like research. It assesses teaching in terms of six core components of scholarly activity—clear goals, adequate preparation, appropriate methods, significant results, effective presentation, and reflective critique—through the use of three "voices" —those of a faculty member, his or her students, and his or her peers. The framework also supports improved teaching, by providing mechanisms for assessment to help faculty to improve in their practices. These framework categories are held constant across all departments; however, the interpretation of these categories and their relative weights would be defined at a department-by-department level, thus specifying in a clear way what is meant by "multiple measures." This would provide the university with a common approach to assessment while preserving disciplinary identity and specificity.

Fin

Much more at: *per.colorado.edu*