Physics Education Research:

a resource for educational transformation at a critical time

2nd Conference on Transforming Research in Undergraduate STEM Education

4 Jun 2012

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PER@C

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National Science Foundation
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American Association of Physics Teachers
Physics Teacher Education Coalition
American Institute of Physics
American Physical Society
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NSF
American Association of Physics Teachers
The William and Flora Hewlett Foundation
Physics Teacher Education Coalition
American Institute of Physics
APS
National Math + Science Initiative
HHMI Howard Hughes Medical Institute

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Ian Caldwell
Ian Her Many Horses
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John Basey
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Juan Ramirez
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Kim Trenbath
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Stephen Butler
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Steve Pollock
Susan Hendrickson
Teresa Foley
Tiffany Ito
Travis Lund
Trish Loeblein
Tyler Schelpat
Ulaff (?) Benjamin
Uma Swamy
Valerie Otero
Valerie Williams
Victoria Hand
Virginia Ferguson
Wahab Baouchi

physics pedagogy astronomy biology mathematics geology chemistry engineering
D
Based
Education
Re
This week:
Integrating STEM Education
UNIVERSITY OF COLORADO BOULDER

What will 50m. get us?

National scene / need

Context as a newish & key tool in PER

A few key studies from CU

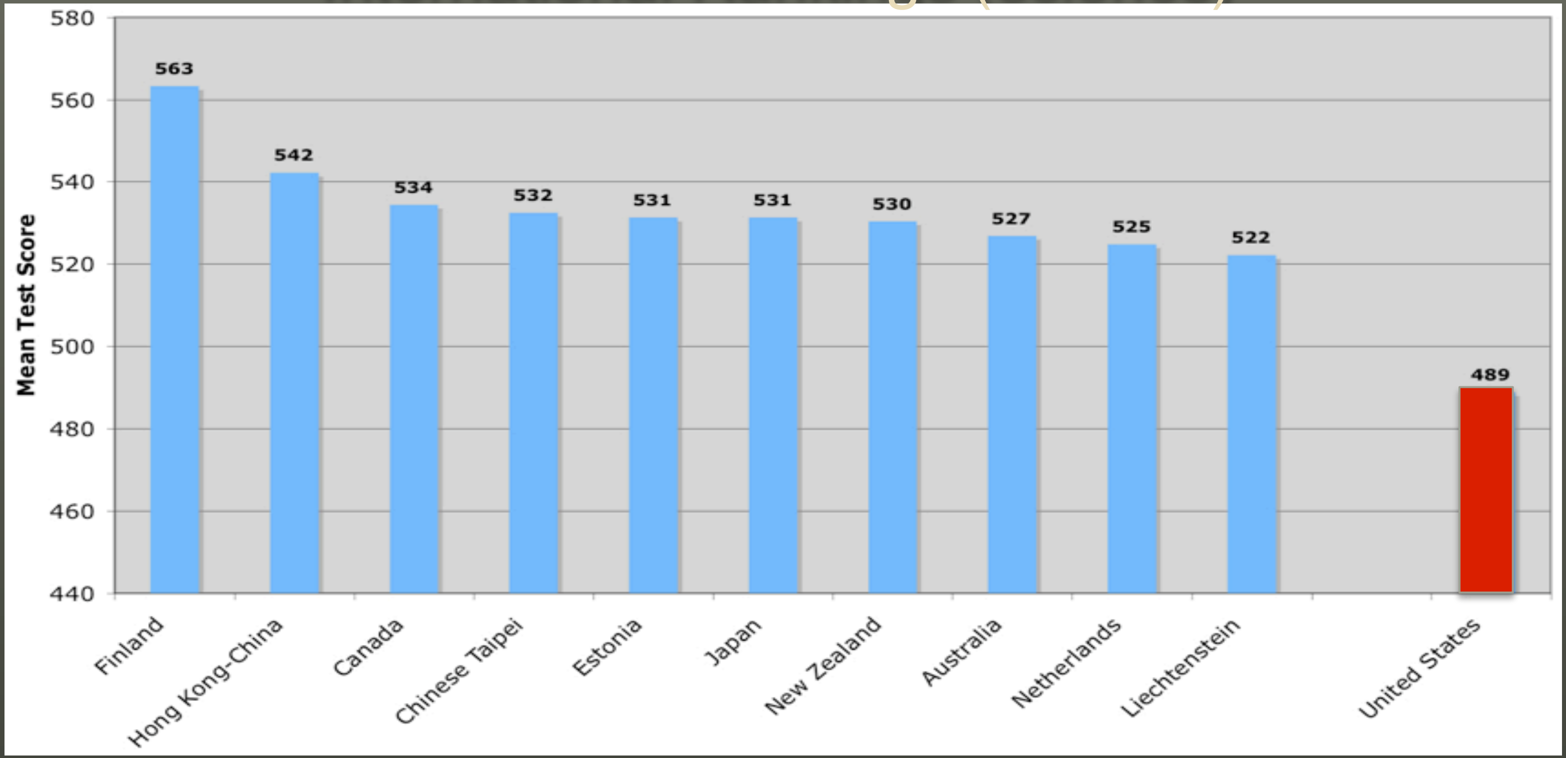
How we all can build on these results…

Grand Challenges in US Education

Better education

U.S. ranks:
21 out of 30 in science
25 out of 30 in math
- PISA 2006

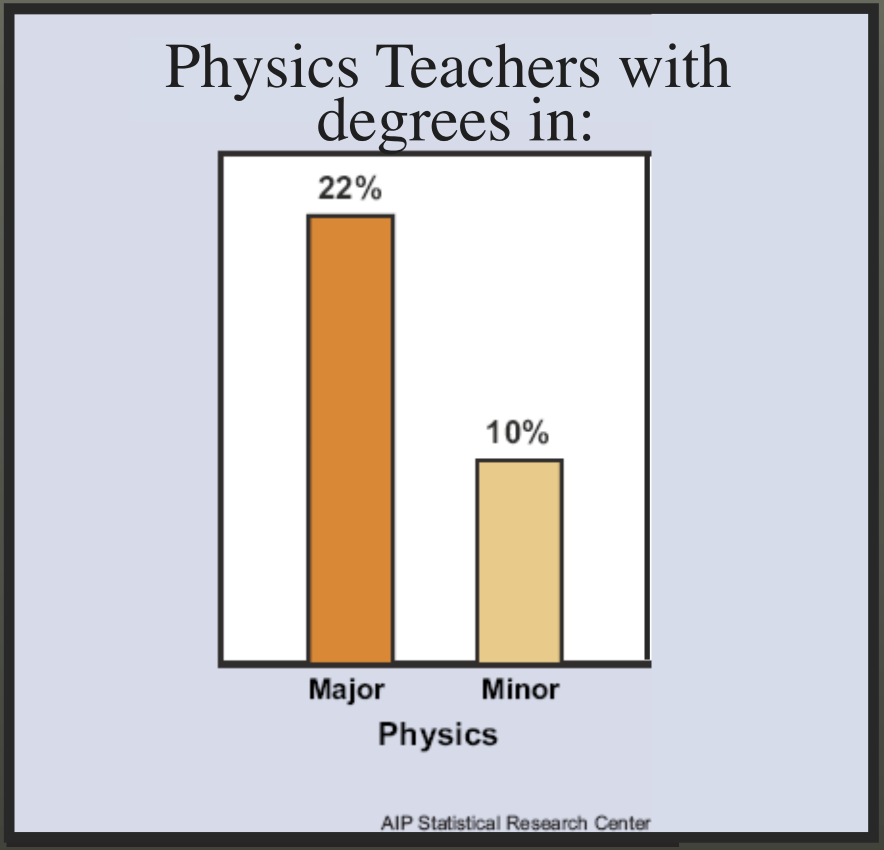
International Rankings (science)



Grand Challenges in US Education

Better education
More and better teachers

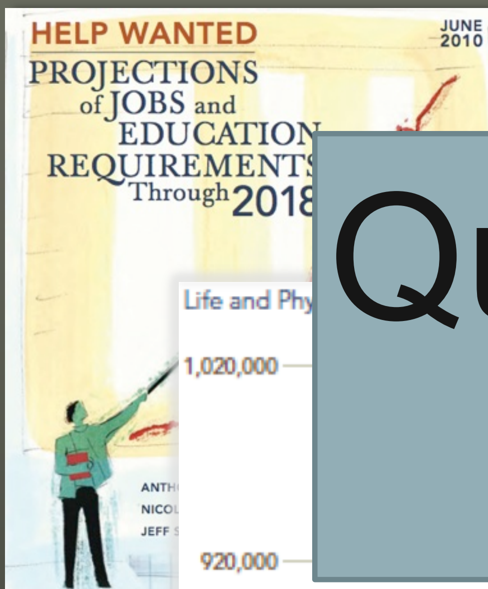
2/3 Physics Out of Field
Less than 50% stay

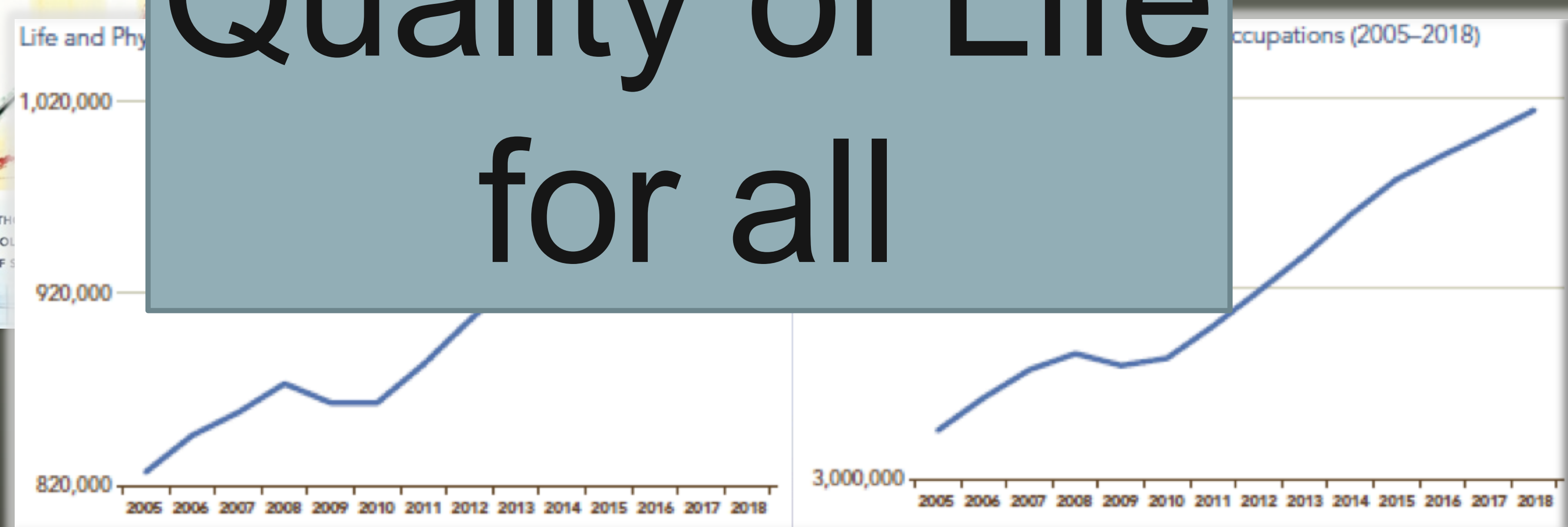


Grand Challenges in US Education

Better education
More and better teachers
More and better STEM grads

1 Million more STEM grads
needed by 2018
and growing



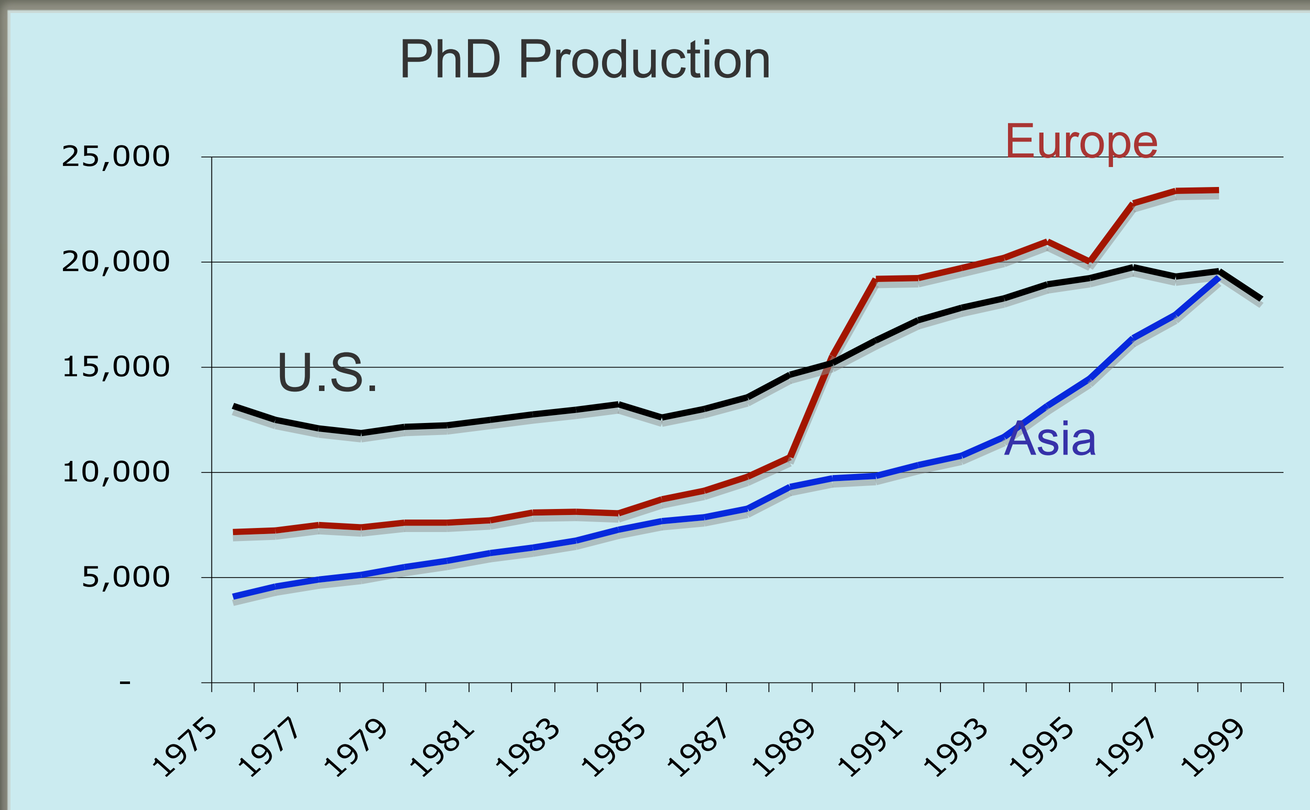


Quality of Life
for all

Grand Challenges in US Education

Better education
More and better teachers
More and better STEM grads
Higher education & research

US surpassed by Europe and Asia in S&E PhD production



A result of poor policy?

Not Just Historical

APS NEWS

A PUBLICATION OF THE AMERICAN PHYSICAL SOCIETY • WWW.APS.ORG/PUBLICATIONS/APSNEWS/INDEX.CFM

October 2011
Volume 20, No.9
www.aps.org/publications/apsnews

APS physics

APS Picks Minority Scholars
see page 6

Physics Programs Face the Axe at Seven Texas Universities

By Michael Lucibella

Seven public universities in Texas are being told they have to phase out their physics undergraduate degrees, with three more being put on two-year probation. In an attempt to make the system more efficient, the Texas Higher Education Coordinating Board (THECB), which oversees Texas' 24 public universities, recently reviewed all of its public university's under-

fied programs that produced fewer than an average of five undergraduates per year between 2006 and 2010 that they needed to reevaluate their programs by June. The programs that received a warning had the option to shut down altogether, combine their program with another degree or apply for a two-year temporary exemption to try and increase enrollment.

"What we are looking at is low producing programs," said Mac-

across the state found to be low producing, 307 requested temporary exemptions, 93 proposed a plan for consolidating degrees, and 145 offered to phase out their programs altogether. Eighty-seven of the requests for exemptions were denied.

Physics programs at Midwestern State, Prairie View A&M, Tarleton State, Texas Southern, University of Texas-Brownsville and West Texas A&M are all losing their

A Era of Significant Attention:
the National Academies

A Era of Significant Attention:
Congress & the White House

One Hundred Eleventh Congress
of the
United States of America

Winning the Race to Educate Our Children

Science, Technology, Engineering, and Mathematics (STEM) Education in the 2012 Budget

"Maintaining our leadership in research and technology is crucial to America's success. But if we want to win the future – if we want innovation to produce jobs in America and not overseas – then we also have to win the race to educate our kids."

President Barack Obama
January 2011

Education, and Science Reauthorization Act of 2010".

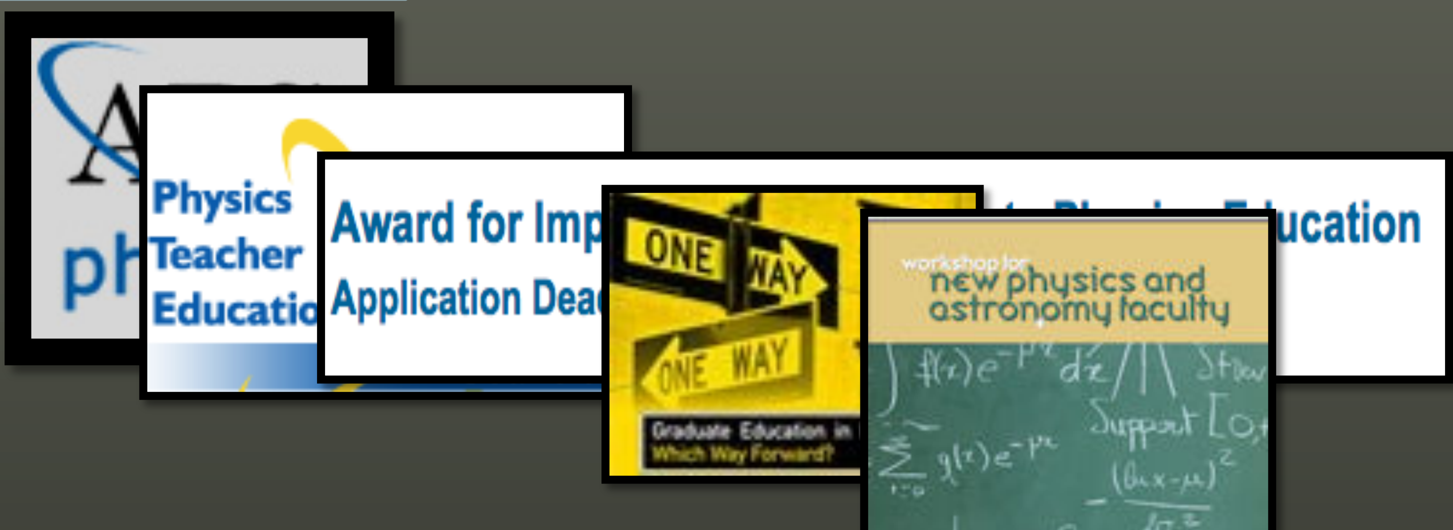
A Era of Significant Attention:
Professional Societies

Association of American Universities
Five-Year Initiative for Improving Undergraduate STEM Education

September 14, 2011

Association of Public and Land-Grant Universities

SMTI Science & Mathematics Teacher Imperative

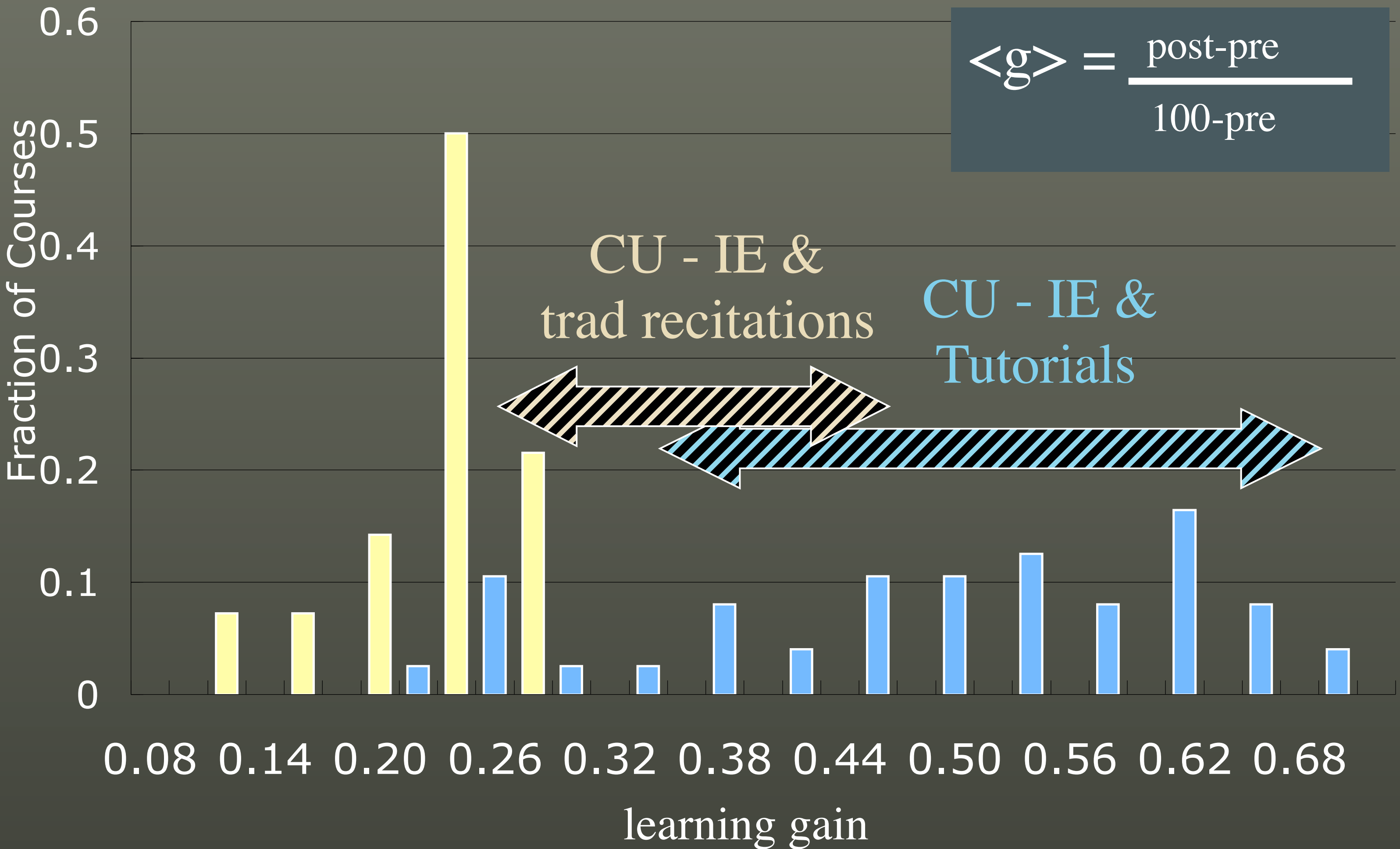


High Education & Disciplines: a key lever in education

Physics Education Research

Course Transformation: Engagement in Learning

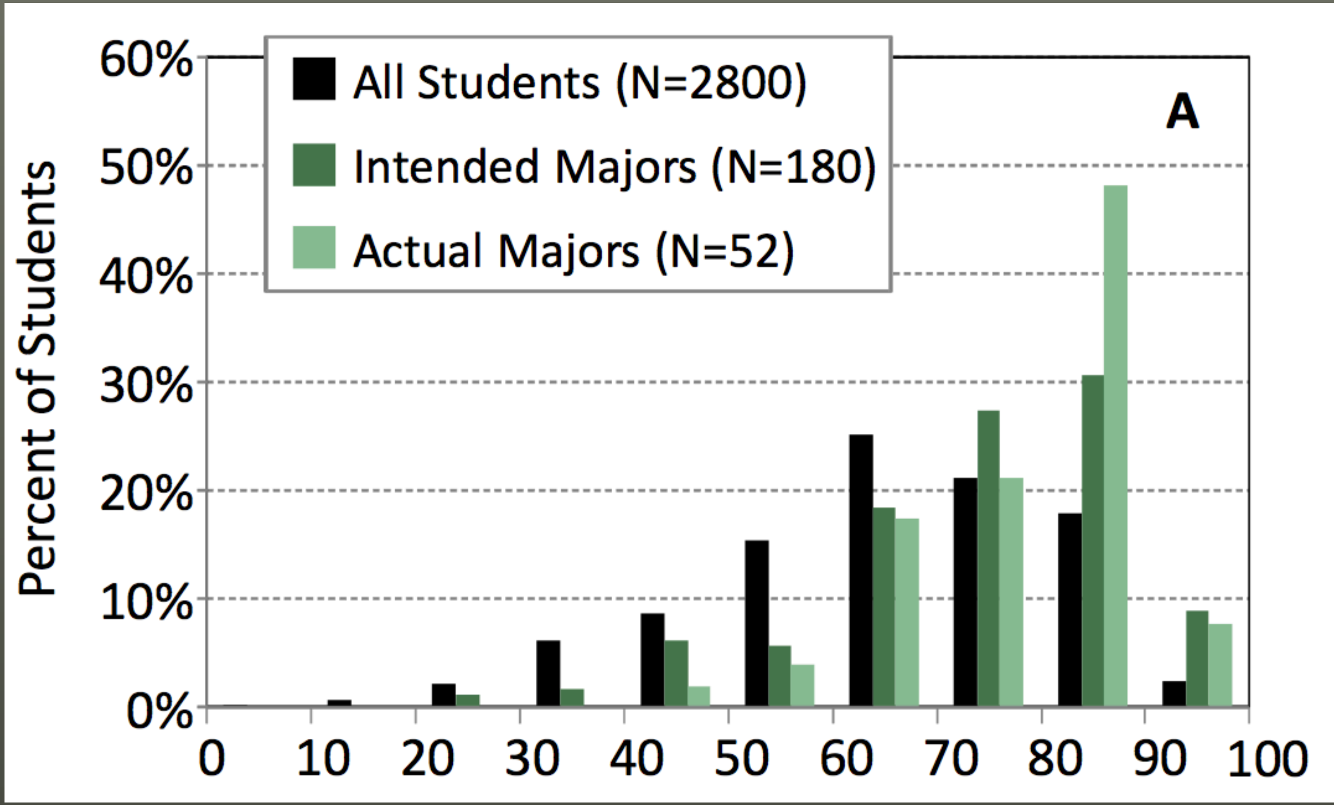
traditional lecture interactive engagement



Pollock & Finkelstein, Physical Review, 4, 010101 (2008).

Students Attitudes and Beliefs

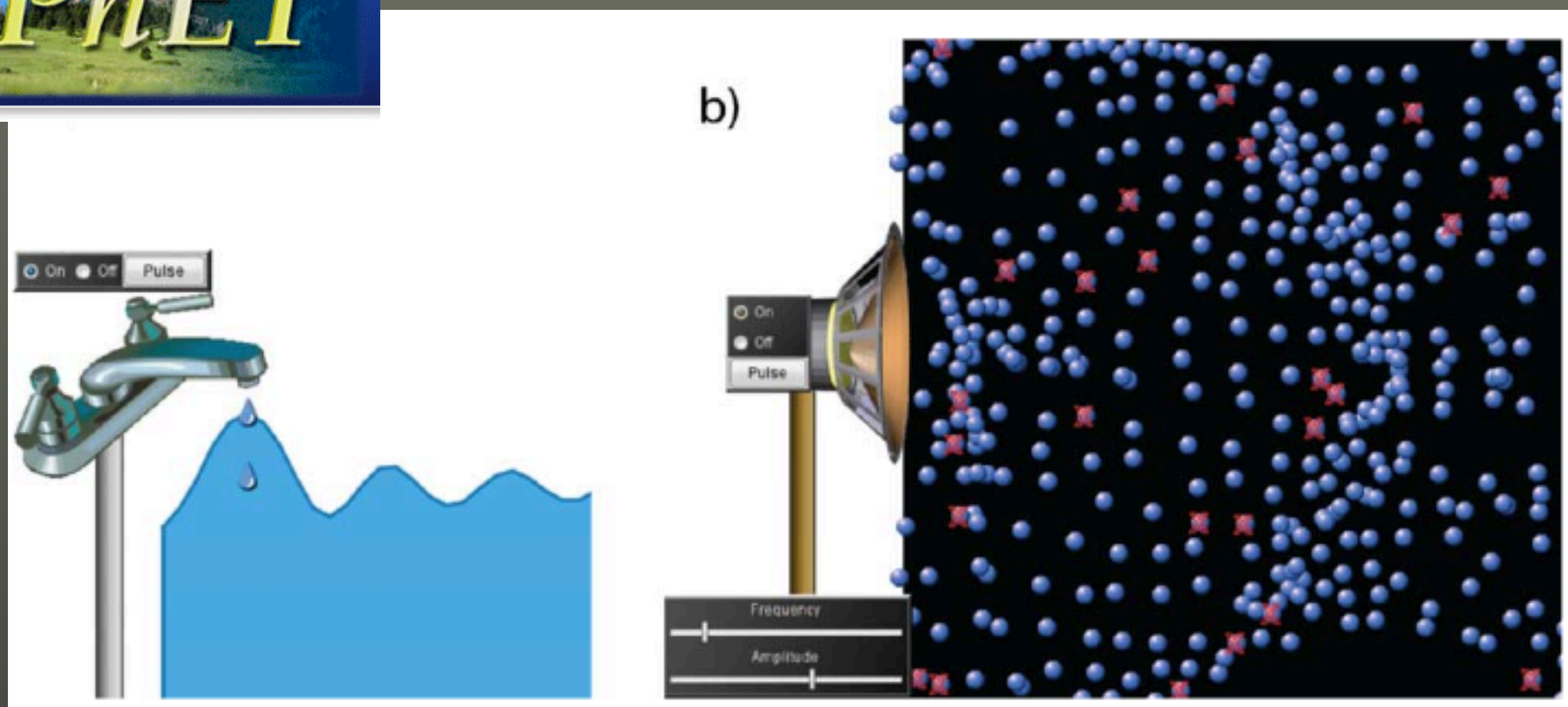
Selecting vs. Breeding Physics Majors



% Favorable CLASS score 1st Semester

PERC 2010, Perkins & Gratny

Designing Effective Simulations

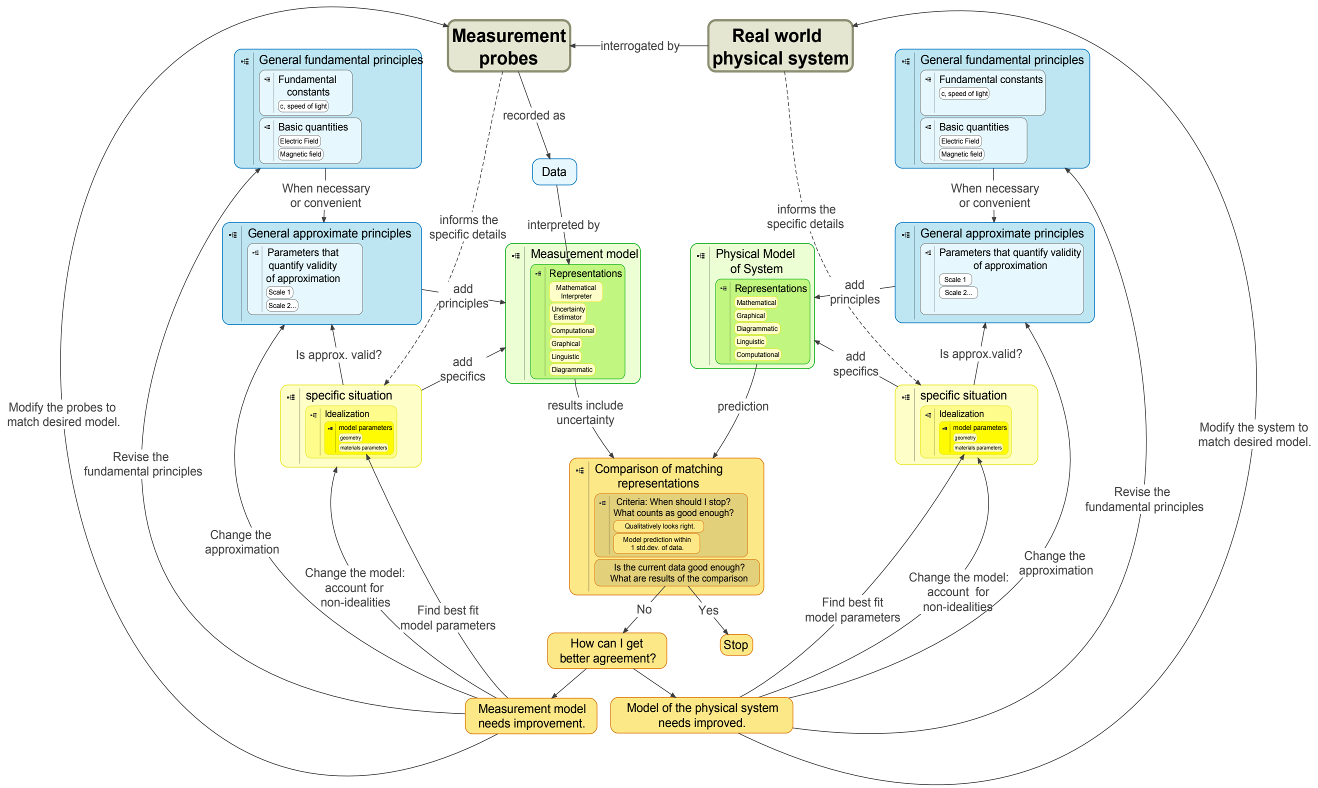


Podolefsky, 2010 PRSTPER

Designing & studying effective Experimental labs

Modeling cycle in laboratory experiments (draft)

Benjamin Zwickl, Heather Lewandowski, Noah Finkelstein
Physics Education Research Group at CU-Boulder

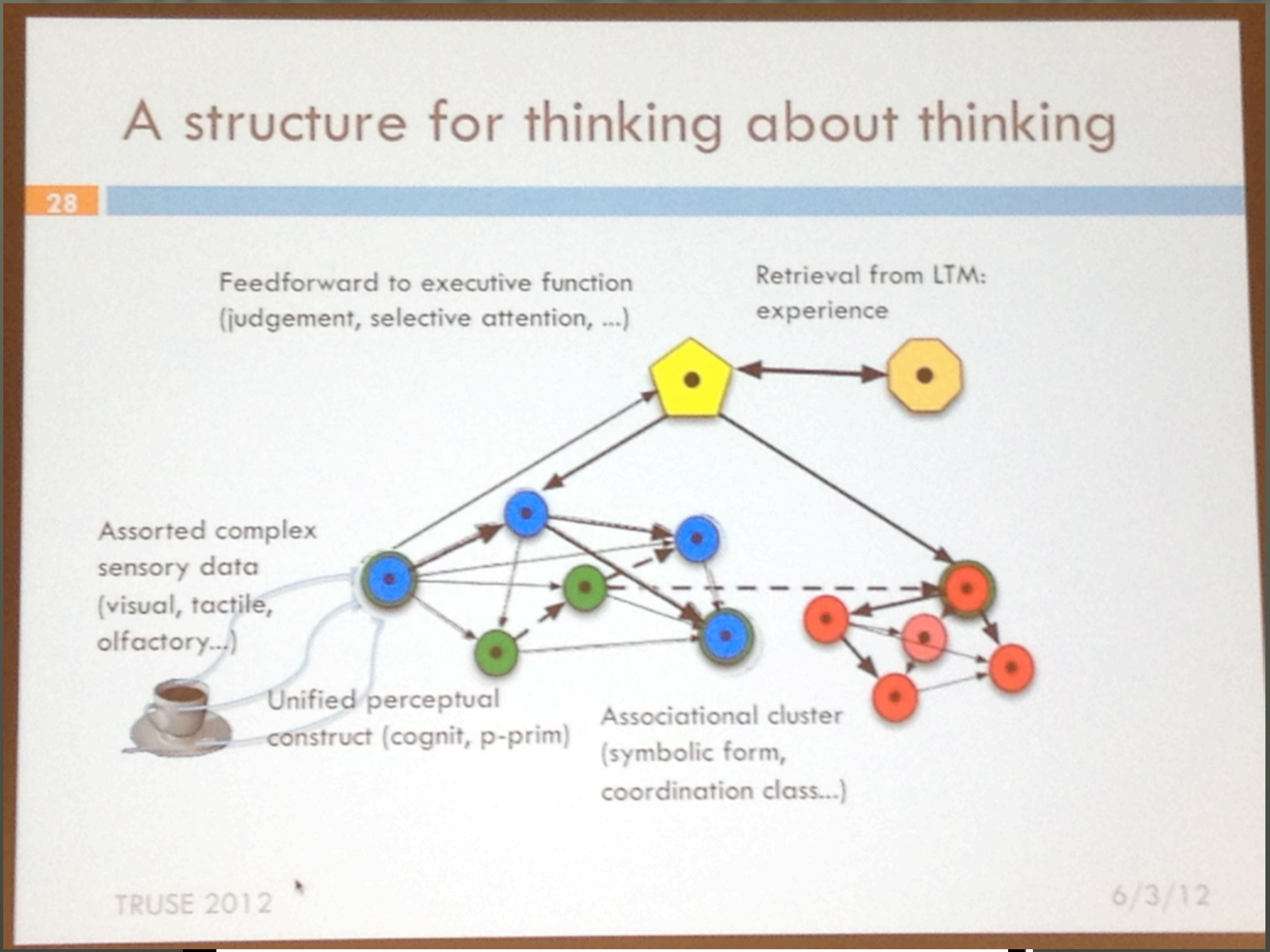


The pathways show how models are developed and used during the ubiquitous lab activity of comparing theoretical predictions with real data. The left half of the cycle represents the model of the measurement system, and is refined through calibration of the device. The right half of the cycle represents the model of the physical system.

examining the how and the why…

focusing on context

Towards a Standard Model



Department of Physics
University of Maryland
College Park MD 20742-4111

Trad'l Model of Education

transmissionist

Individual $\xleftarrow[\text{transmission}]{\text{Instruction via}}$ Content (e.g. circuits)

Built in to our classes?

PER Theoretic Background

transmissionist

Individual $\xleftarrow[\text{via transmission}]{\text{Instruction}}$ Content (E/M)

constructivist

Individual $\xleftrightarrow[\text{construction}]{\text{Active}}$ Content

Prior knowledge

PER Theoretic Background

transmissionist

Individual $\xleftarrow[\text{via transmission}]{\text{Instruction}}$ Content (E/M)

basic constructivist

Individual $\xleftrightarrow[\text{constructivist}]{\text{Construction}}$ Content (E/M)

Prior knowledge

Contextual constructivist

Tools / Instructor . . .

Individual $\longleftrightarrow$ Content (E/M)

Prior knowledge
Attitudes and Beliefs
Student background
Affect

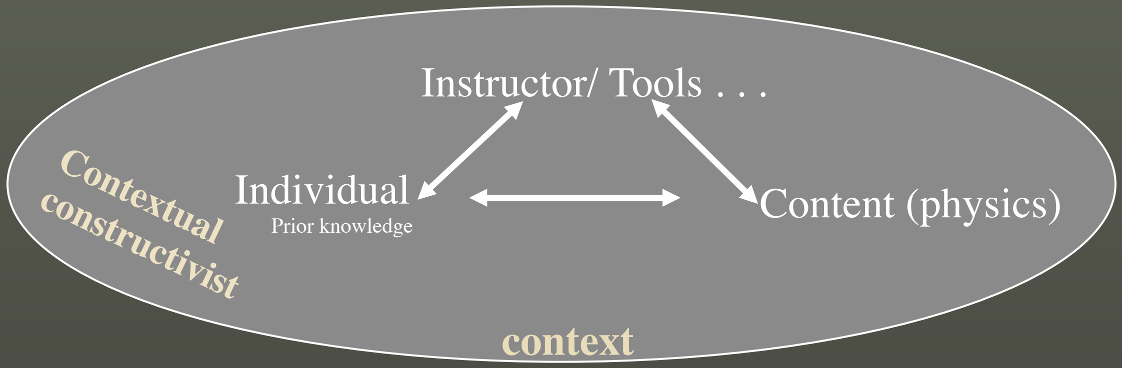
context

Finkelstein, N. (2005) Context in the Context of Physics Education, *IJSE*
Finkelstein, N. (2005-2011). NSF CAREER Grant: REC# 0448176

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

<u>Theorem</u>: If a moving particle, carried uniformly at
constant … then the
time inte… the ratio of
their dist…

(foll…).

algebra

$$\frac{d_1}{d_2} = \frac{\cancel{r} * t_1}{\cancel{r} * t_2} \quad \Rightarrow \quad \frac{t_1}{t_2} = \frac{d_1}{d_2}$$

From diSessa (2000) *Changing Minds*

A 2nd Example

$$\frac{7960.0}{10} = \boxed{796.0}$$

Easy!

$$\frac{7960.0}{16} = \boxed{\text{Hard(er)}} \Rightarrow \frac{\text{1F18.0}}{10} = \boxed{\boxed{\text{1F1.8}}}$$

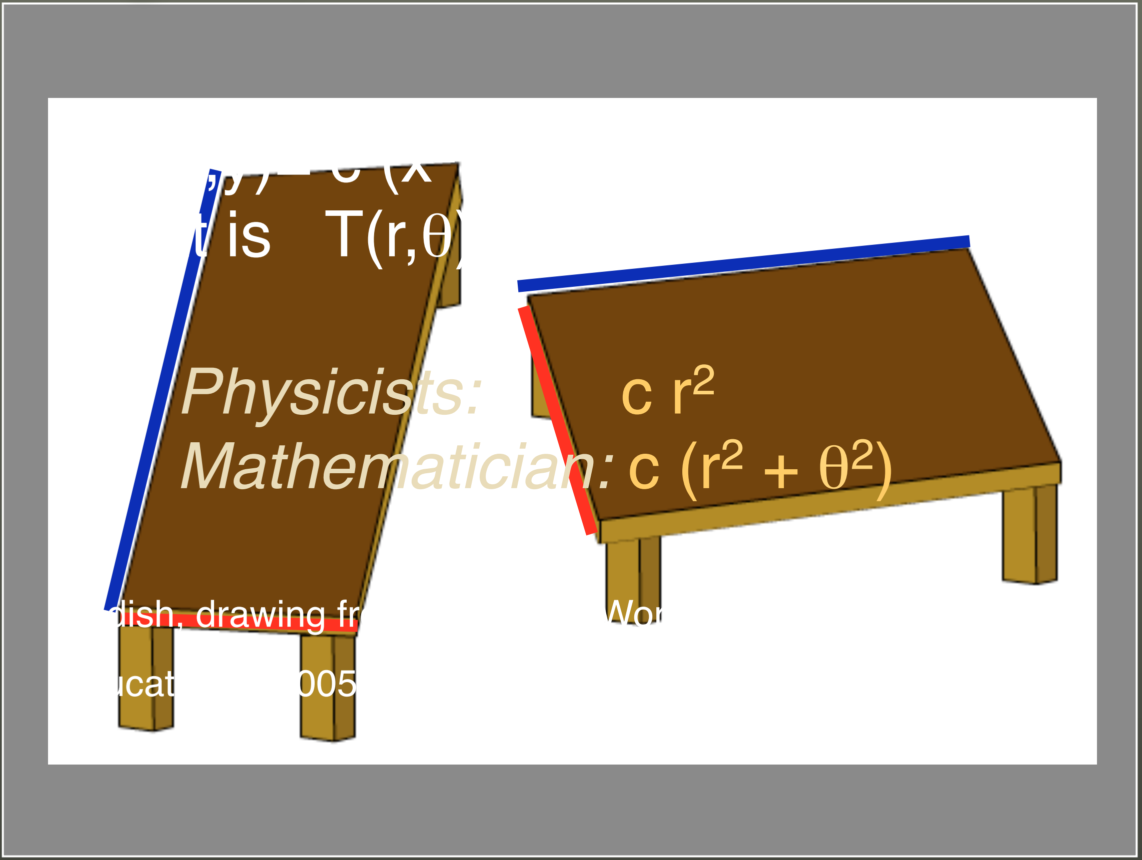
Decimal (Base 10)

Hex (Base 16)

Meaning of tools

Evolutionary (biological):

And cultural:

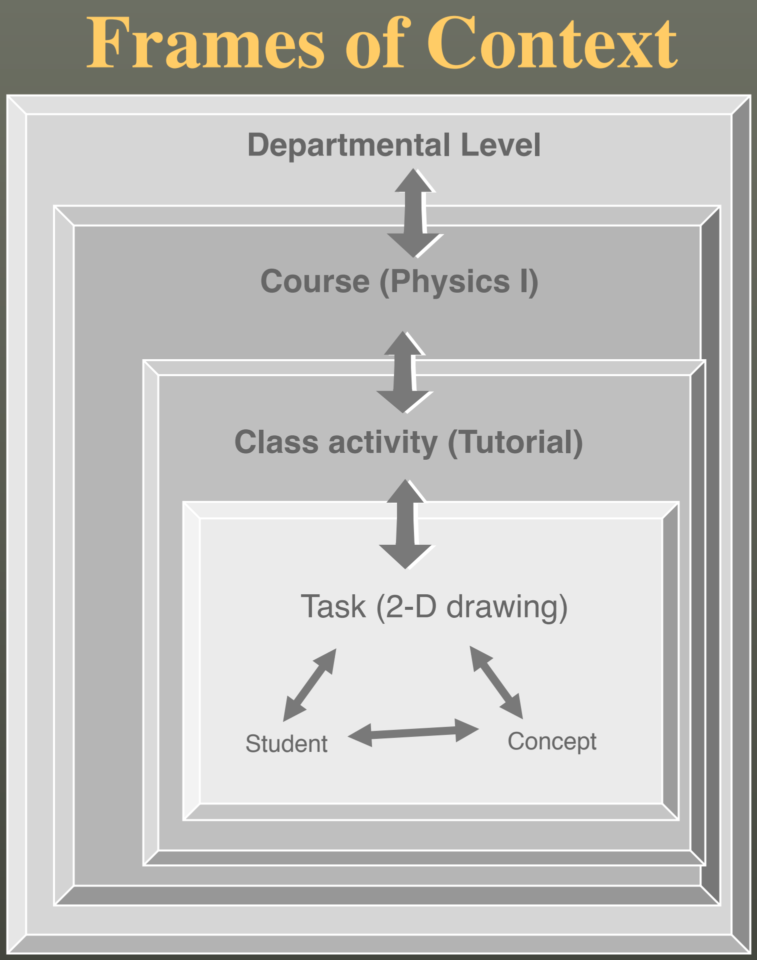


Thinking in terms of tools

- **Material or intellectual**
- **Historically rooted**
- **Come with predispositions of use**
- **Our capacities shapes our use of tools**

Wartofsky, M. (1973). *Models*. Dordrecht: D. Reidel.
Cole, M. (1996) *Cultural Psychology*

Embedded Context(s)



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, et al. *J. of Online Learn & Teaching* 2, 3 109 (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

Artifact / 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.

Sample applications

Artifact / Frame of context	i. Tools	ii. Practices	iii. Norms
a. Individ'l	Representation & Analogy; Use in the Classroor	Learning by teaching	CLASS- Student attitudes and beliefs (ABs)
b. Course			
c. Depart'l	Faculty us based mater		of dept'l ns

Transforming Courses:

sion

Impacts of Faculty Variation

A Framework for models of STEM educational change

with Chandra Turpen (2010)

With SPollock, K. Perkins, H. Lewendowski, B. Zwickl

with P. Kohl (2007) and N. Podolefsky (2008)

with Andrea Beach & Charles Henderson

NSF 0448176, CAREER: Physics Education and Contexts of Student Learning.

Sample applications

Artifact / Frame of context	i. Tools	ii. Practices	iii. Norms
a. Individ'l	F	earning by teaching	CLASS- Student attitudes and beliefs (ABs)
b. Course	S U	urse Practices licker Use Tutorials	Secondary adaptation of reforms
c. Depart'l	Faculty use of PER-based materials	Programs in grad, p.d., and fac prep CU STOMP	Influence of dept'l norms

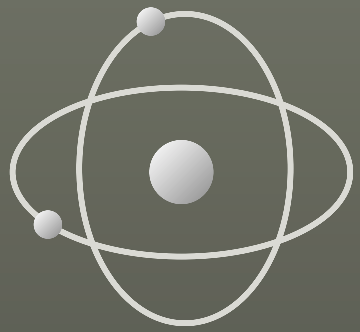
Representation & Analogy; Use in the Classroom

with P. Kohl (2007) and N. Podolefsky (2008)

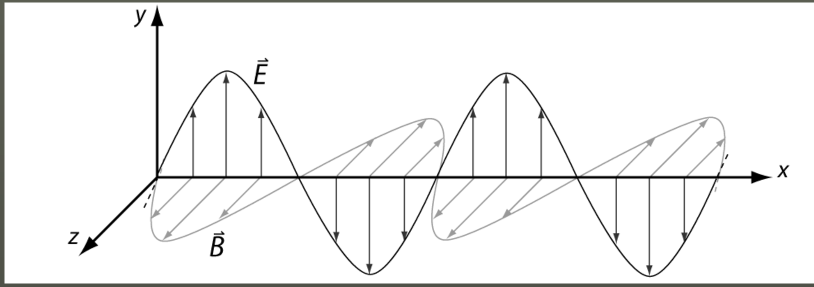
NSF 0448176, CAREER: Physics Education and Contexts of Student Learning.

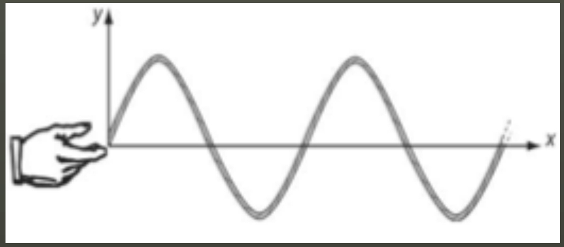
Student reasoning using tools

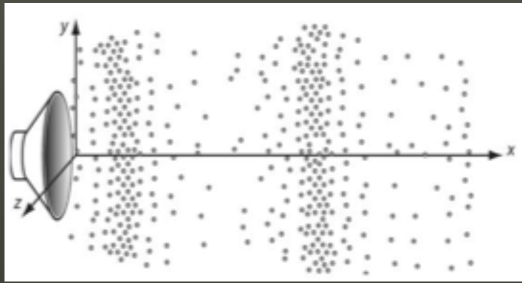
Role of representation



Utility of analogies

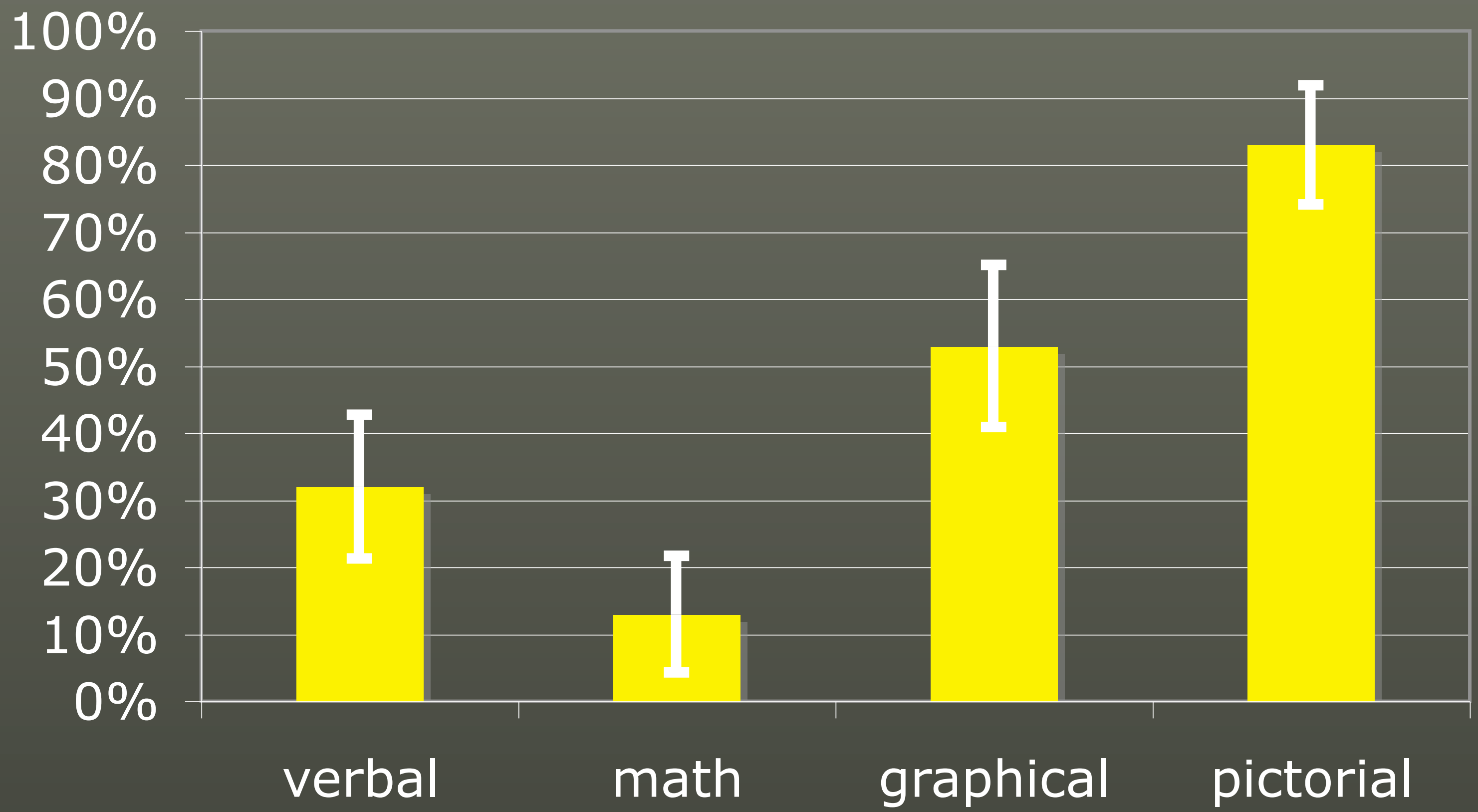






Student competence given representational format

Atomic physics quiz

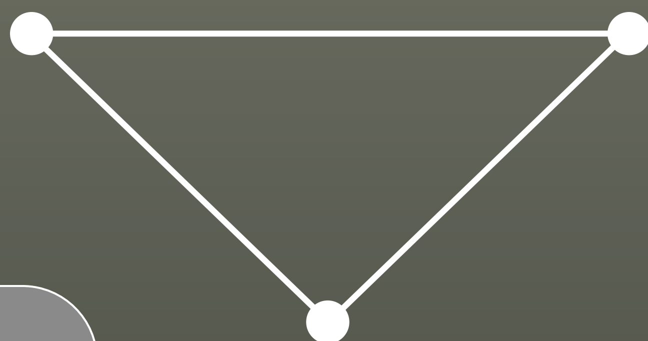


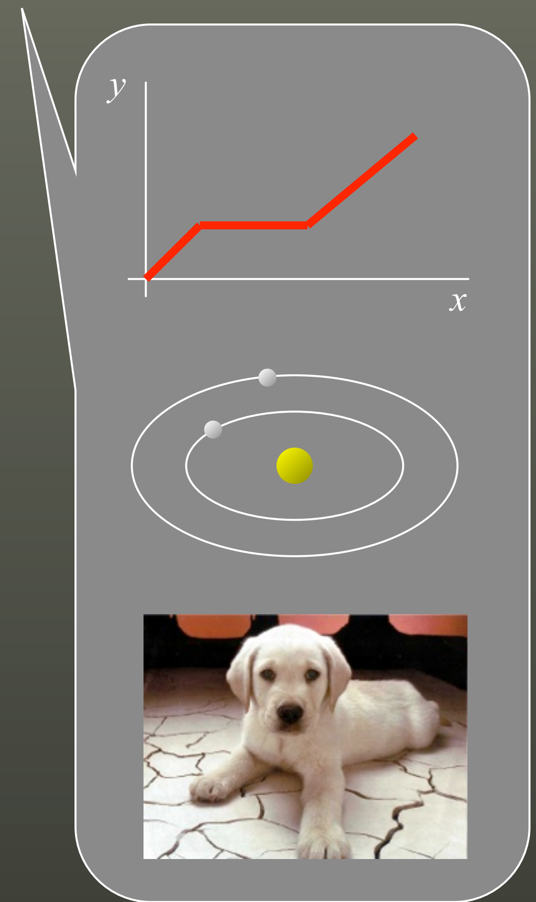
Kohl and Finkelstein (2005). Phys Rev,1, 010104

Using Reps and Cueing

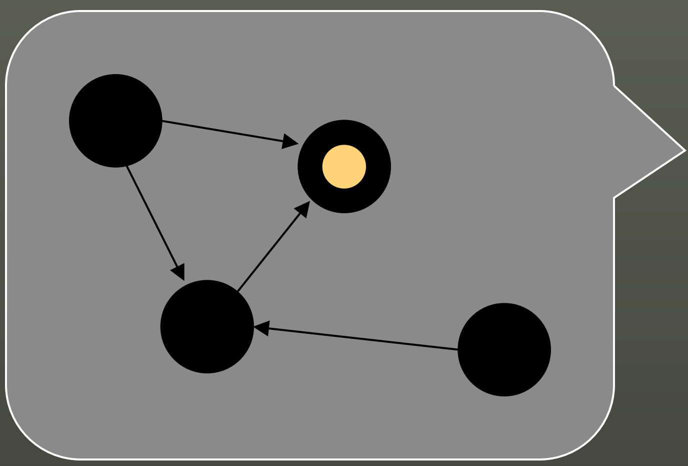
REFERENT

Representation



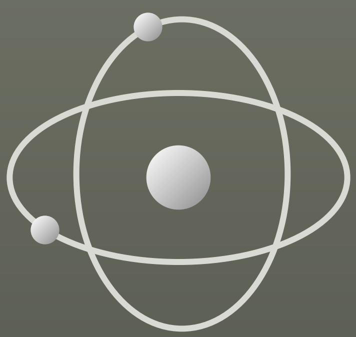


Schema

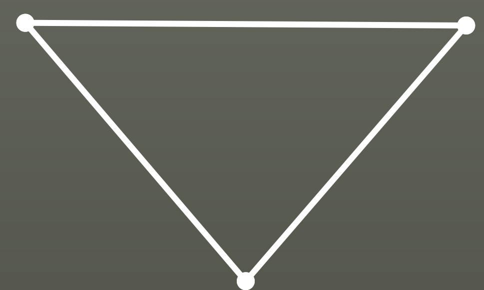


Podolefsky and Finkelstein, Phys Rev: ST PER (2006; 2007)
Adapted from Roth and Bowen (1999)

Bohr's Atom



ATOM

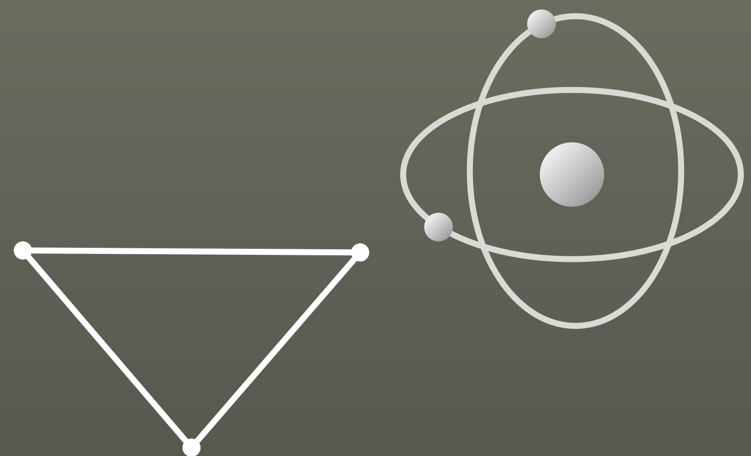


Electron *revolves around* nucleus

Nucleus *attracts* electron

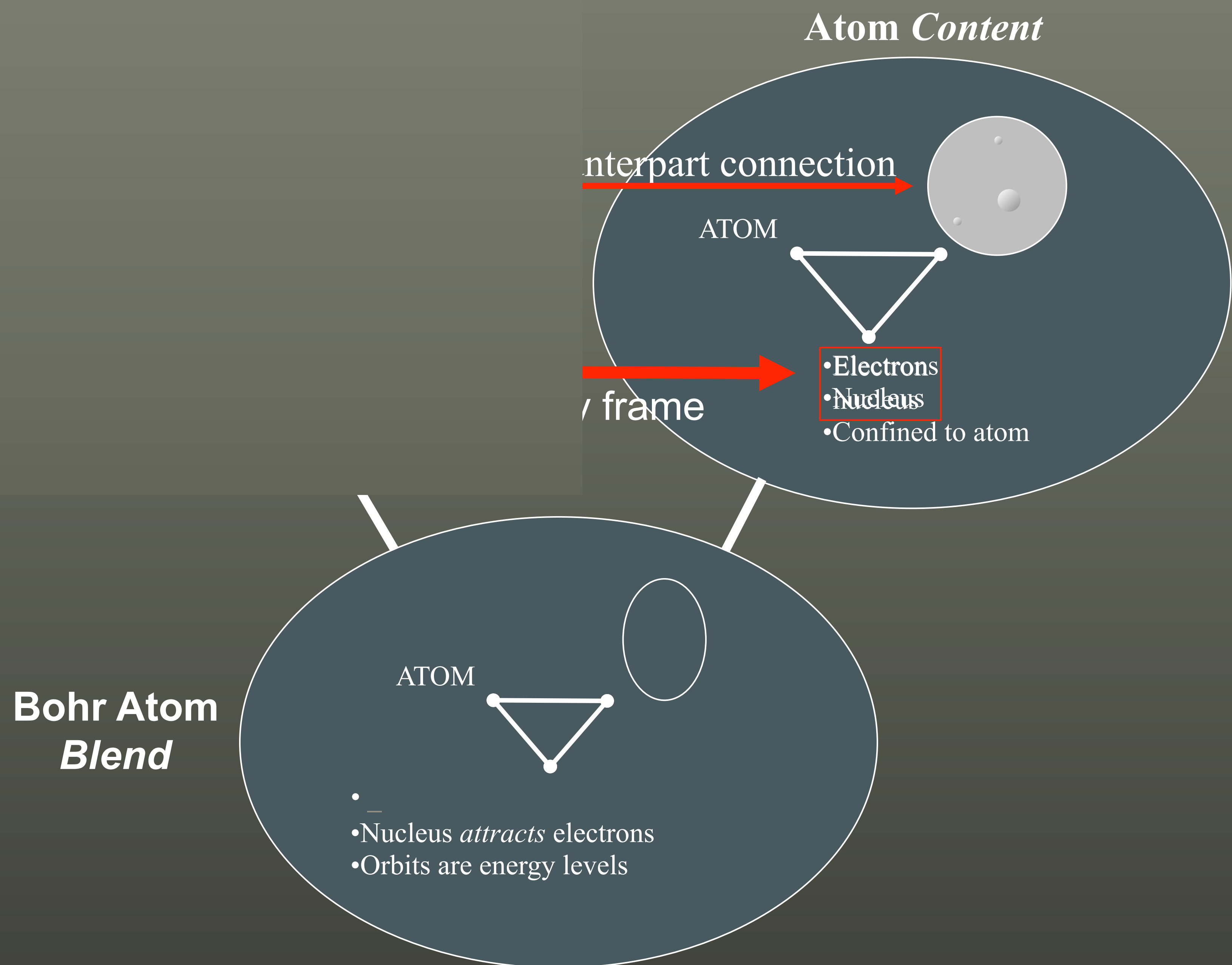
How do we connect representations, objects, schema?

ATOM



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

blending & layering



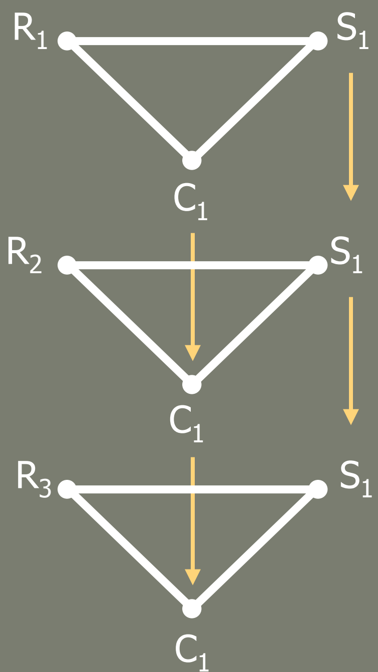
Podolefsky and Finkelstein, Phys Rev: STPER (2007)

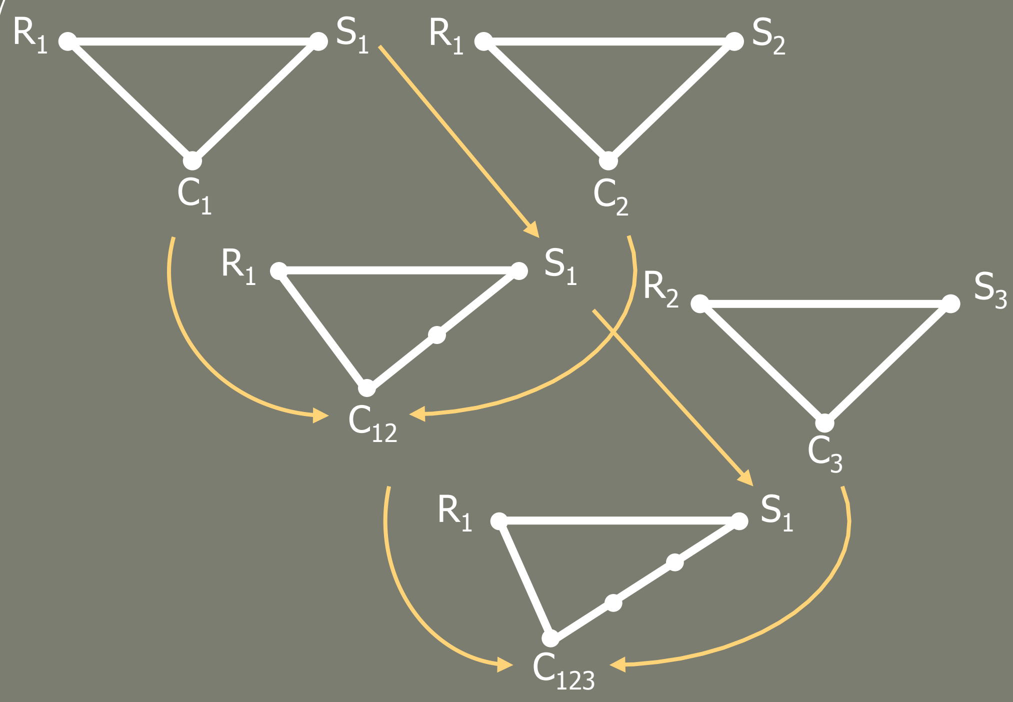
Adapted from Fauconnier & Turner (2002)

Analogical Scaffolding

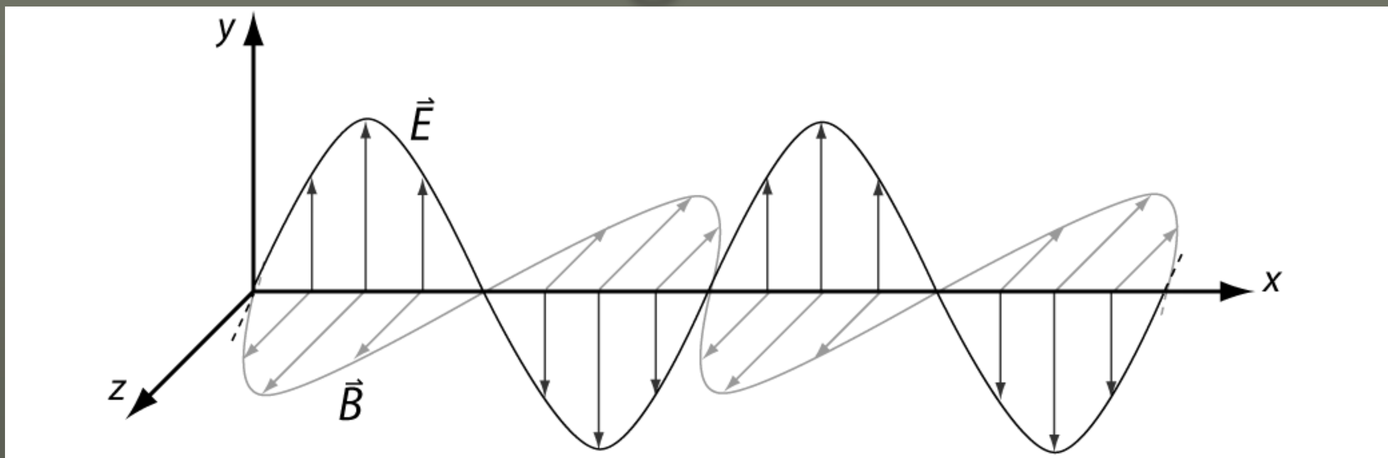
Layering Blends to Make Meaning

R_i = Referents
S_i = Signs
C_i = Schemas





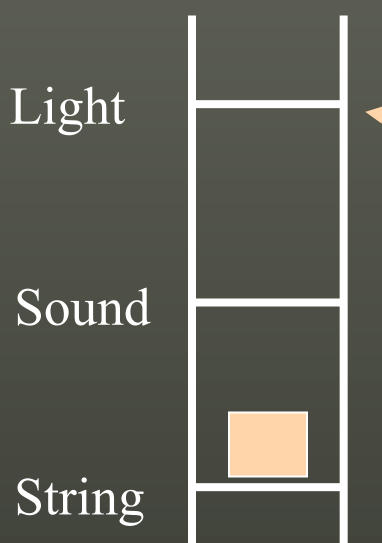
Apply to curriculum: teaching abstract concept

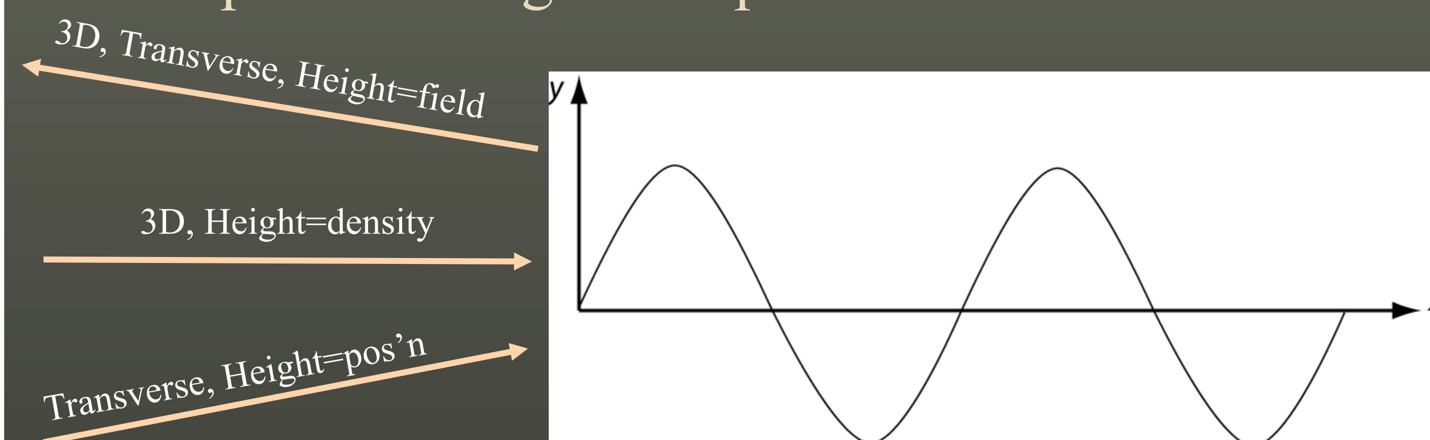


EM Wave

- 3D
- Transverse
- Field
- Propagating

Compile meaning into representation





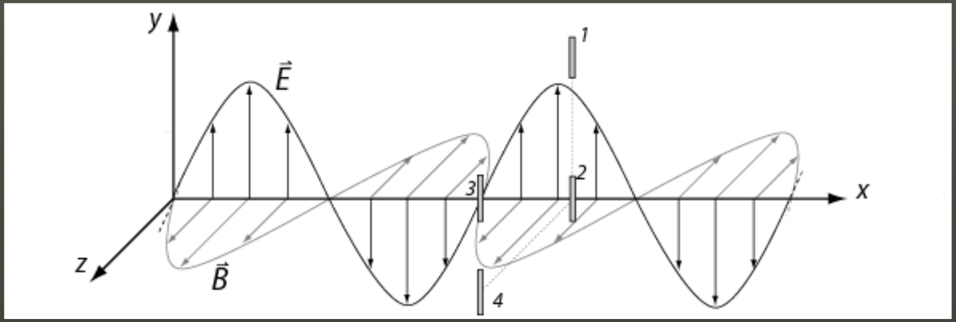
Podolefsky and Finkelstein (2006). Phys Rev, 2,2, 020101

The study

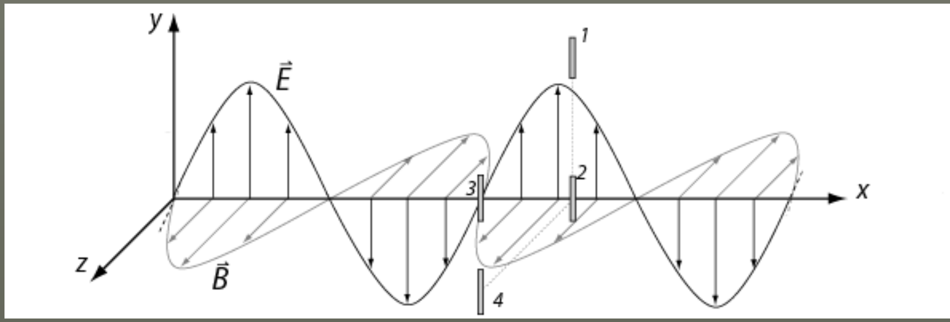
Large scale study: calc-based physics, E/M
modified *Tutorials in Intro Physics*

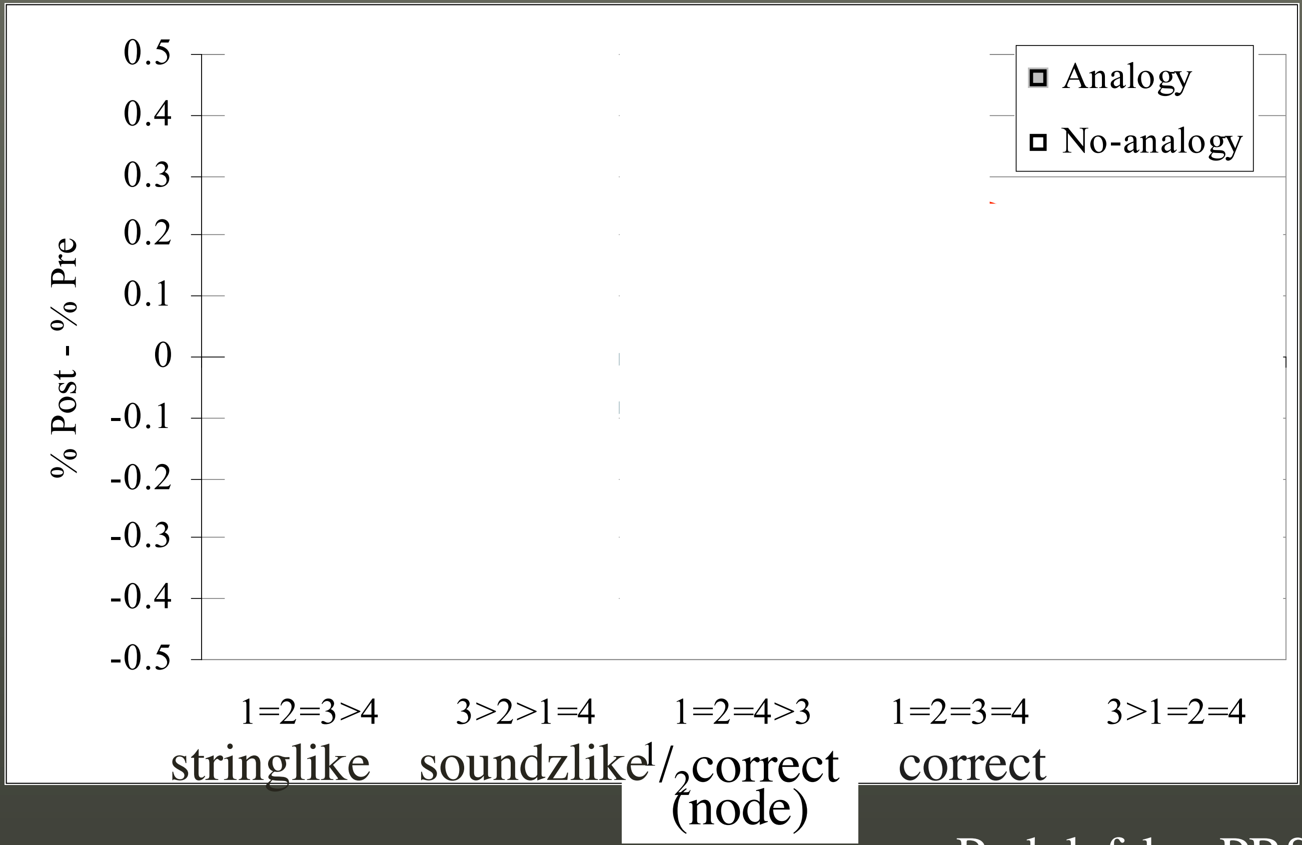
	Analogy (N=72)	No-Analogy (N=74)
Part I: Basic wave props	String	E/M
Part II: Plane wave / 3D	Sound	E/M
Part III: E/M wave as field	E/M	E/M
		(UW approach)

Pre / Post Assessment: rank time averaged signal at antennas



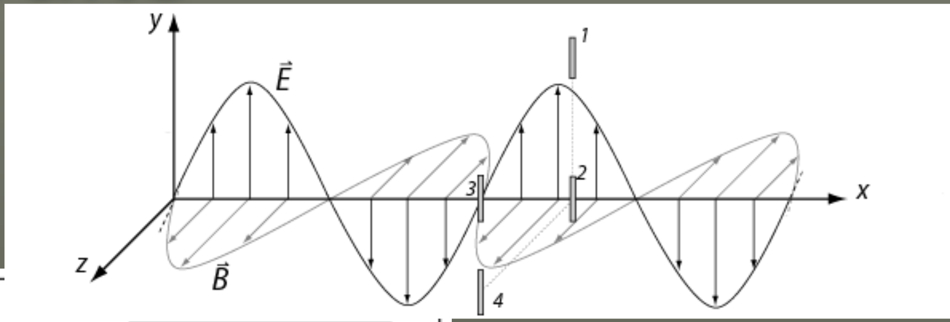
Results

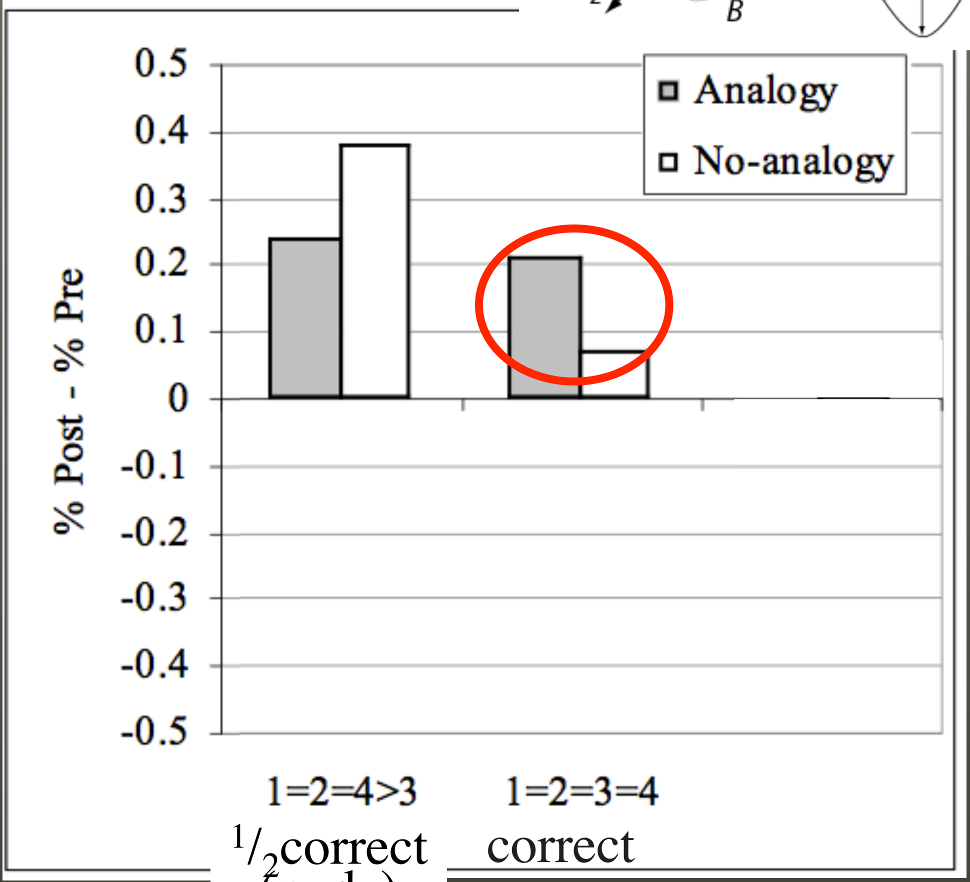




Podolefsky, PRST – PER 2007

Results





$^1/_2$correct (node)

correct

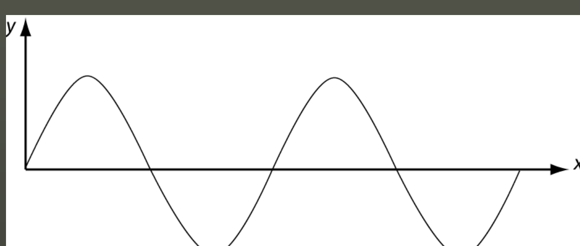
Podolefsky, PRST – PER 2007

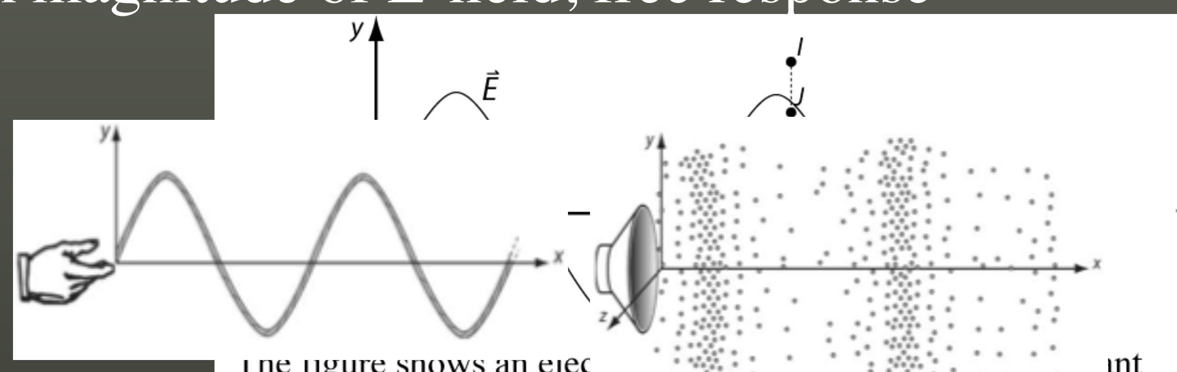
Another Study- Which Reps?

Large scale study: algebra-based physics, E/M
modified *Tutorials in Intro Physics*

		Abstract	Blend
Part I: Basic wave props	(String)	Sine	Sine+Pictorial
Part II: Plane wave / 3D	(Sound)	Sine	Sine+Pictorial
Part III: E/M wave as field	(E/M)	Sine	Sine+Pictorial

Pre / Post Assessment: rank magnitude of E-field, free response



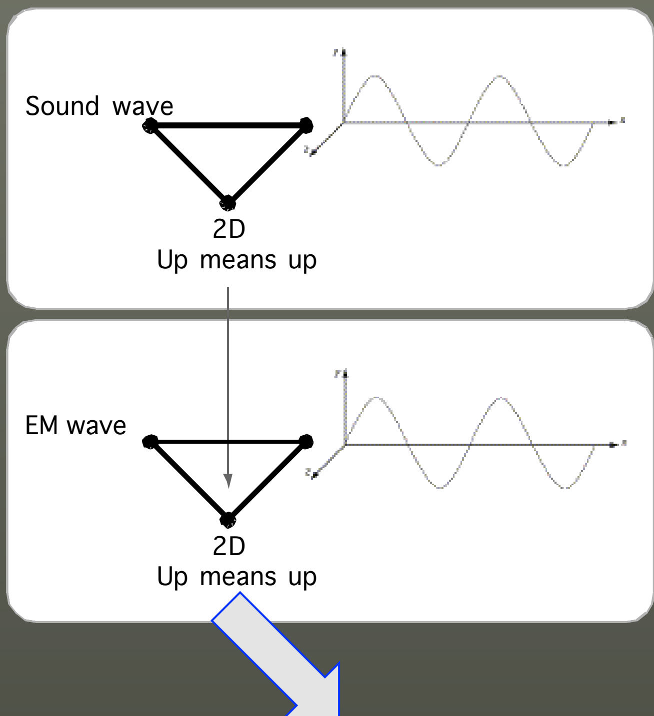


The figure shows an elec ... int
in time. For the instant shown, rank the points I, J, K, and L
according to the magnitude of the electric field at these points.

Adapted from UW *Tutorials*

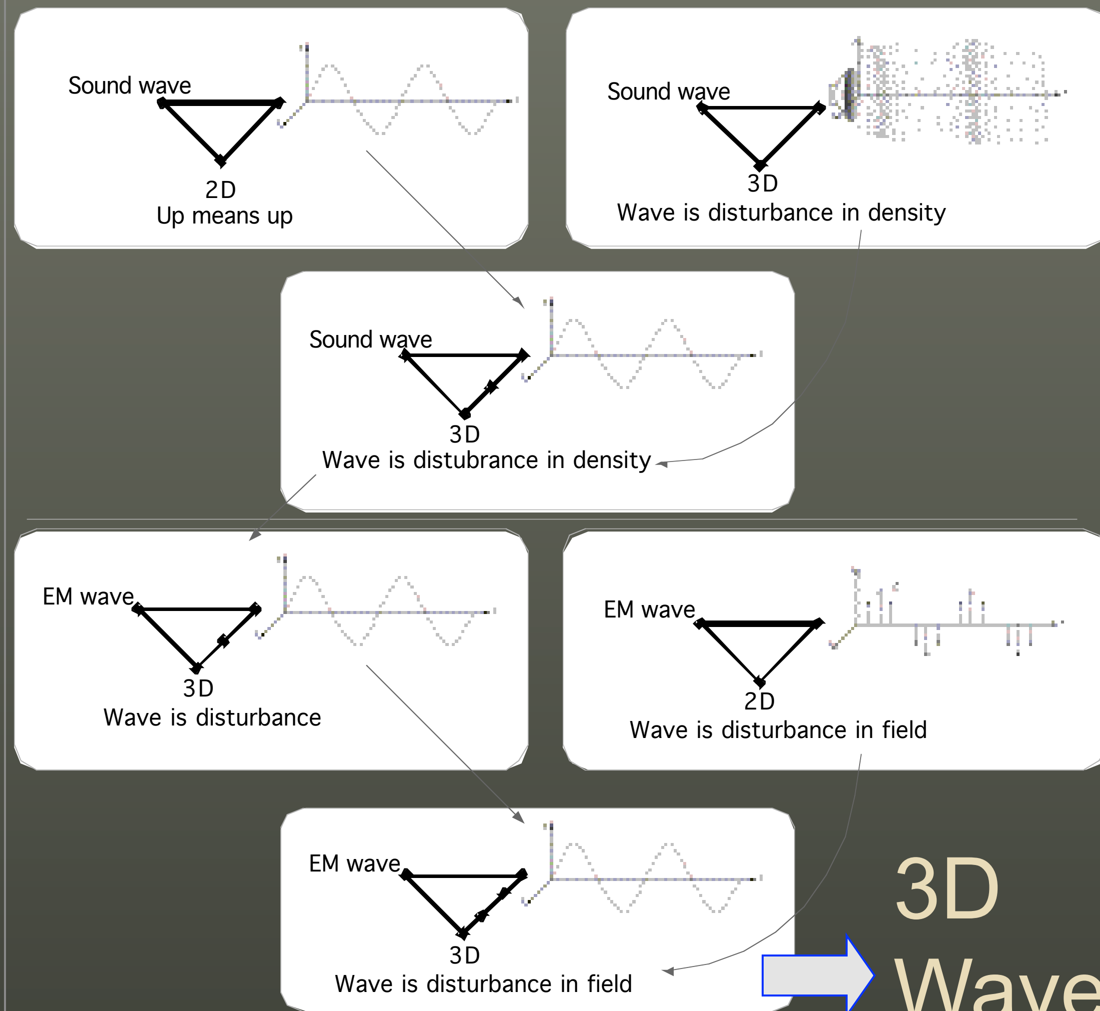
AS Model of Representations

Abstract



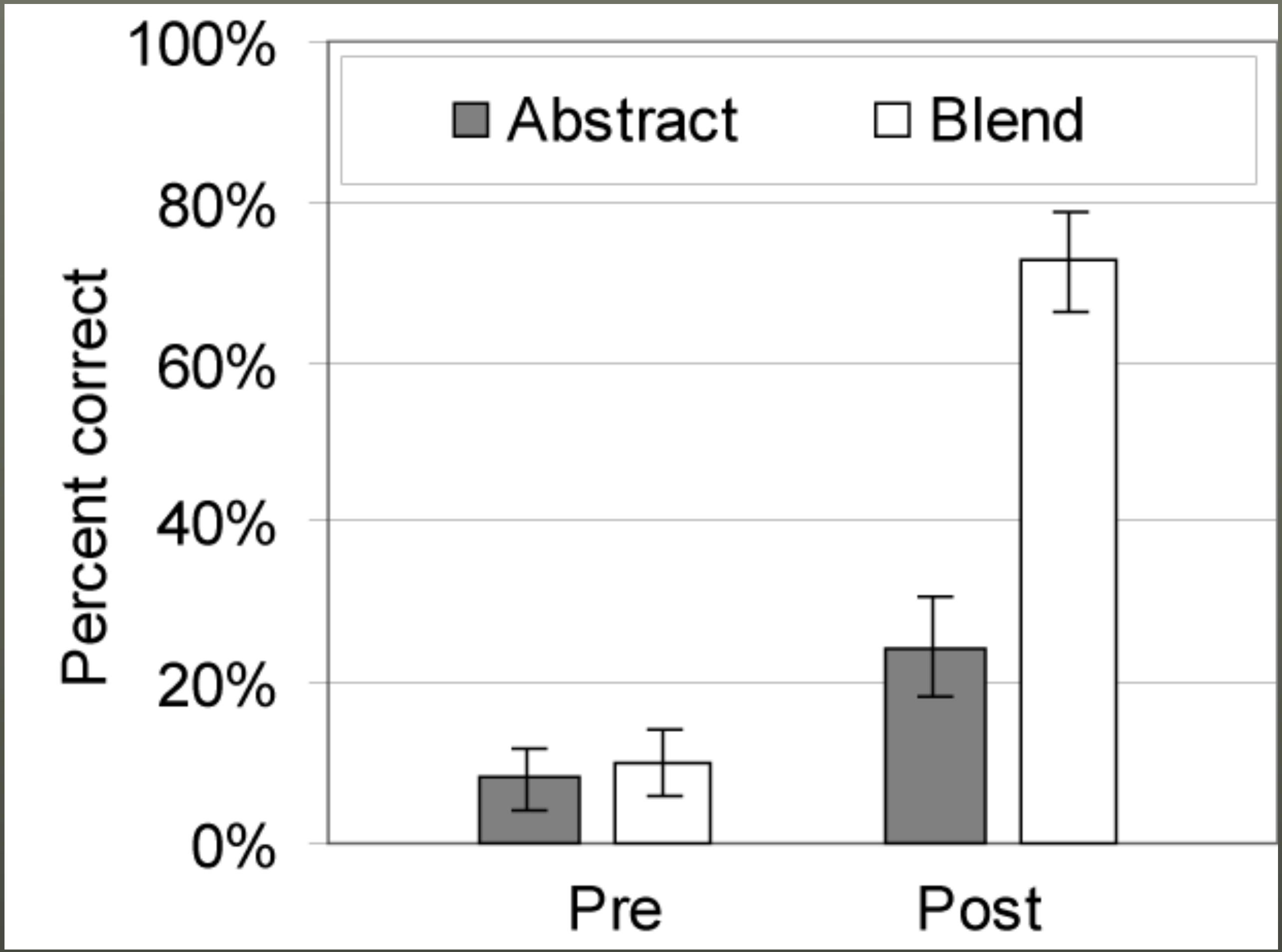
2D Wave

Blend



3D Wave

Results



Podolefsky and Finkelstein, Physical Review: ST PER, 3,2,020104 (2007).

more at: per.colorado.edu/analogy

Sample applications

Theme / Frame of context	i. Tools	ii. Practices	iii. Norms
a. Individ'l	Representation Analogy PhET	Learning by teaching	CLASS- Student attitudes and beliefs (ABs)
b. Course	Studies of Sims, Use of Reps and Anal [illegible]	Course Practices Clicker Use [illegible]	Secondary adaptation of [illegible] eforms
c. Depart'l	Faculty us [illegible] based materials	[illegible] CU STOMP	[illegible] ce of dept'l norms

Impacts of Faculty Variation in *Peer Instruction*

with Chandra Turpen (2010)

Common Model for Research

What happens in the classroom?

Focus on Implementation

GOALS:

1. Identify variation in faculty practices

2. Document impact on:

   - student opportunities,

   - class norms,

   - students' perceptions

Methods

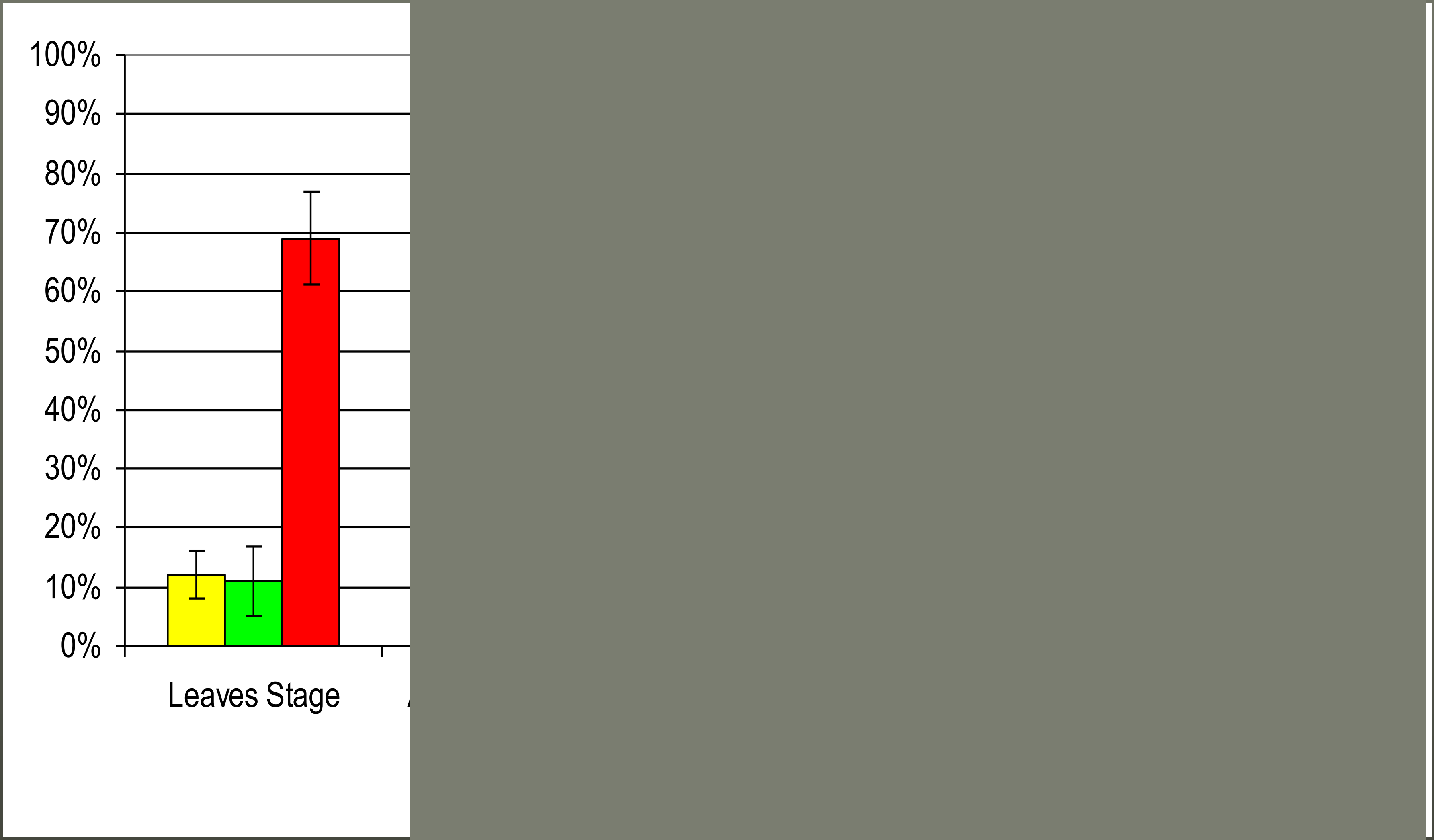
- Student survey data
- Ethnographic Observations
- Audio-recorded files of observed classes
- Daily Clicker Records
- Course documents

Environment and Professors

- 3 undergraduate, large enrollment introductory calc-based physics courses.

- 3 Professors:
  - Yellow (Phys 1): Mentored, Experienced PI user
  - Green (Phys 2): Novice PI user
  - Red (Phys 3): Active in PER, Experienced PI user

Framing of PI by Instructors



Different Opportunities for students

	Yellow	Green	Red
Apply new physical concepts			
Discuss content with peers			

Different Opportunities for students

	Yellow	Green	Red
Apply new physical concepts	●	●	●
Discuss content with peers	●	●	●
Formulate & Ask Questions			●

Different Opportunities for students

	Yellow	Green	Red
Apply new physical concepts	●	●	●
Discuss content with peers	●	●	●
Formulate & Ask Questions			●
Communicate in public forum		●	●

Different Opportunities for students

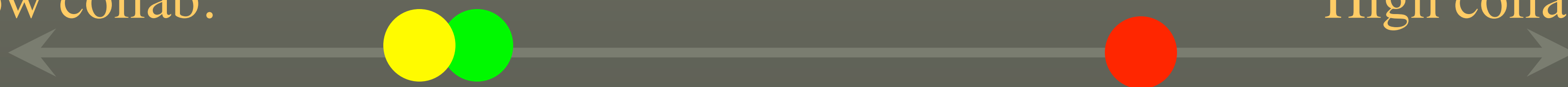
	Yellow	Green	Red
Apply new physical concepts	●	●	●
Discuss content with peers	●	●	●
Formulate & Ask Questions			●
Communicate in public forum		●	●
Evaluate problem solutions			●

Norm: Faculty-student collaboration

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:

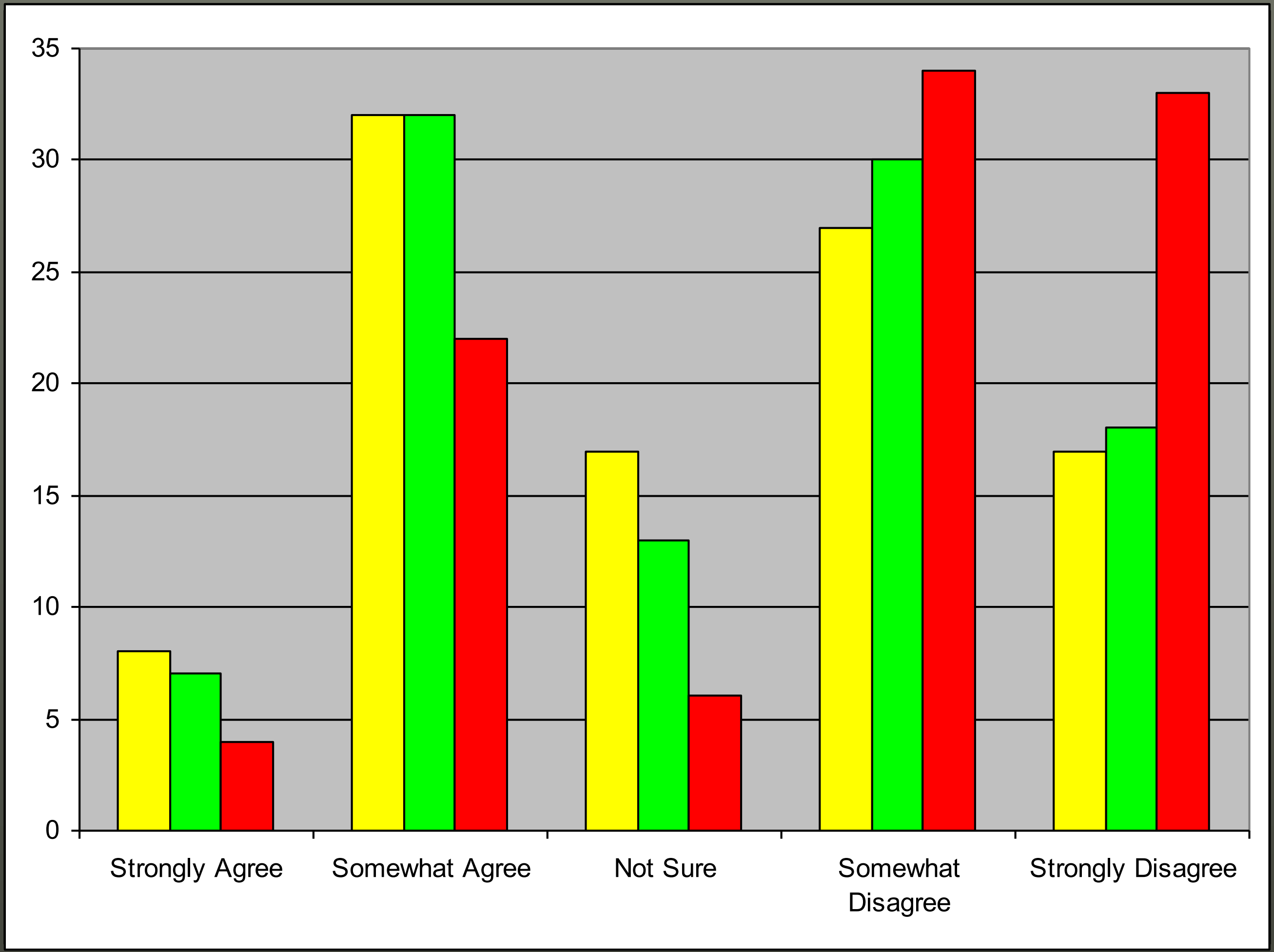
- Rarely (11% of the time) left the stage.
- Occasionally (25% of the time) answered student questions
- Never discussed w/ students
- Always heard student explanations, Usually heard only one correct student explanation
- Usually quick to reveal correctness of student explanation

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

Faculty-Student Collaboration

Q4: Awkward to ask professor questions



Students Perceive Differences

	Yellow-Red	Green-Red	Yellow-Green
Q3: Comfort discussing			
Q4: Awkward Questions			
Q5: ν Speak to Professor			
Q6: ν Ask question			

Students Perceive Differences

	Yellow-Red	Green-Red	Yellow-Green
Q3: Comfort discussing	R p=0.03		
Q4: Awkward Questions	R **p<0.001***		
Q5: Speak to Professor	R **p<0.001***		
Q6: Ask question	R **p<0.001***		

* Significant

Students Perceive Differences

	Yellow-Red	Green-Red	Yellow-Green
Q3: Comfort discussing	↑R p=0.03	↑R **p=0.001***	
Q4: Awkward Questions	↑R **p<0.001***	↑R **p=0.002***	
Q5: Speak to Professor	↑R **p<0.001***	↑R **p<0.001***	
Q6: Ask question	↑R **p<0.001***	↑R **p<0.001***	

* Significant

Students Perceive Differences

	Yellow-Red	Green-Red	Yellow-Green
Q3: Comfort discussing	R p=0.03	R **p=0.001***	Y p=0.03
Q4: Awkward Questions	R **p<0.001***	R **p=0.002***	p=0.6
Q5: Speak to Professor	R **p<0.001***	R **p<0.001***	G p=0.02
Q6: Ask question	R **p<0.001***	R **p<0.001***	G p=0.03

* Significant

Findings from PI Studies

- Faculty members can be distinguished based on their PI practices.
- Students are given different opportunities to engage in scientific practices.
- Differences in PI practices lead to different classroom norms.
- Students' perceive the classroom norms differently in these courses.

Sample applications

Theme / Frame of context	i. Tools	ii. Practices	iii. Norms
a. Individ'l	Representation Analogy PhET	Learning by teaching	CLASS- Student attitudes and beliefs (ABs)
b. Course	Studies of Sims, Use of Reps and Analogies	Course Practices Clicker Use Tutorials	Secondary adaptation of reforms
c. Depart'l	Faculty use o… based mat…	Programs in grad…	…of dept'l …ms

A Framework for models of STEM educational change

with Andrea Beach & Charles Henderson

Facilitating Change in STEM Undergraduate Education

Keeping the Good things Going: Study and Improvement of Change Strategies in STEM Education

Henderson, C., Beach, A., & Finkelstein, N. (2011) Facilitating Change in Undergraduate STEM Instructional Practices: An Analytic Review of the Literature, *Journal of Research in Science Teaching*, **48** (8), 952-984.

Starting Point: Current State of Knowledge

- We know a lot about:
  - effective teaching and learning of STEM subjects
  - how to apply this knowledge in individual classrooms

Now all STEM classrooms produce knowledgeable, skilled students who have positive attitudes toward science …

The Big Question

How to encourage the spread of research-based ideas to all instructors/ classrooms?

Facilitating Change in STEM Undergraduate Education

295 Articles
(in original data set)

- 108 Different Journals
- Most Common:
  - Innovative Higher Education (26 articles)
  - Higher Education (21 articles)
  - Journal of Research in Science Teaching (13 articles)
  - Studies in Higher Education (12 articles)
  - Change (10 articles)
  - College Teaching (8 articles)
  - Teaching in Higher Education (7 articles)
  - Journal of Faculty Development (6 articles)

Categorized along two Important Dimensions

- 1. What does the change effort intend to directly impact?

Individuals	Environments and Structures
personal characteristics of single individuals, such as beliefs, knowledge, behaviors, etc.	impact characteristics of the system such as rules, physical characteristics of the environment, norms, etc.

Categorized along two Important Dimensions

2. To what extent is the outcome prescribed in advance?

Prescribed Final State	Emergent Final State
final state is known at the beginning of process	final state is developed

Facilitating Change in STEM Undergraduate Education

Each Strategy has a Unique Emphasis

Individuals

DEVELOPING
Curriculum & Pedagogy

DEVELOPING
Reflective Teachers

Prescribed Final Condition

Emergent Final Condition

DEVELOPING
Policy

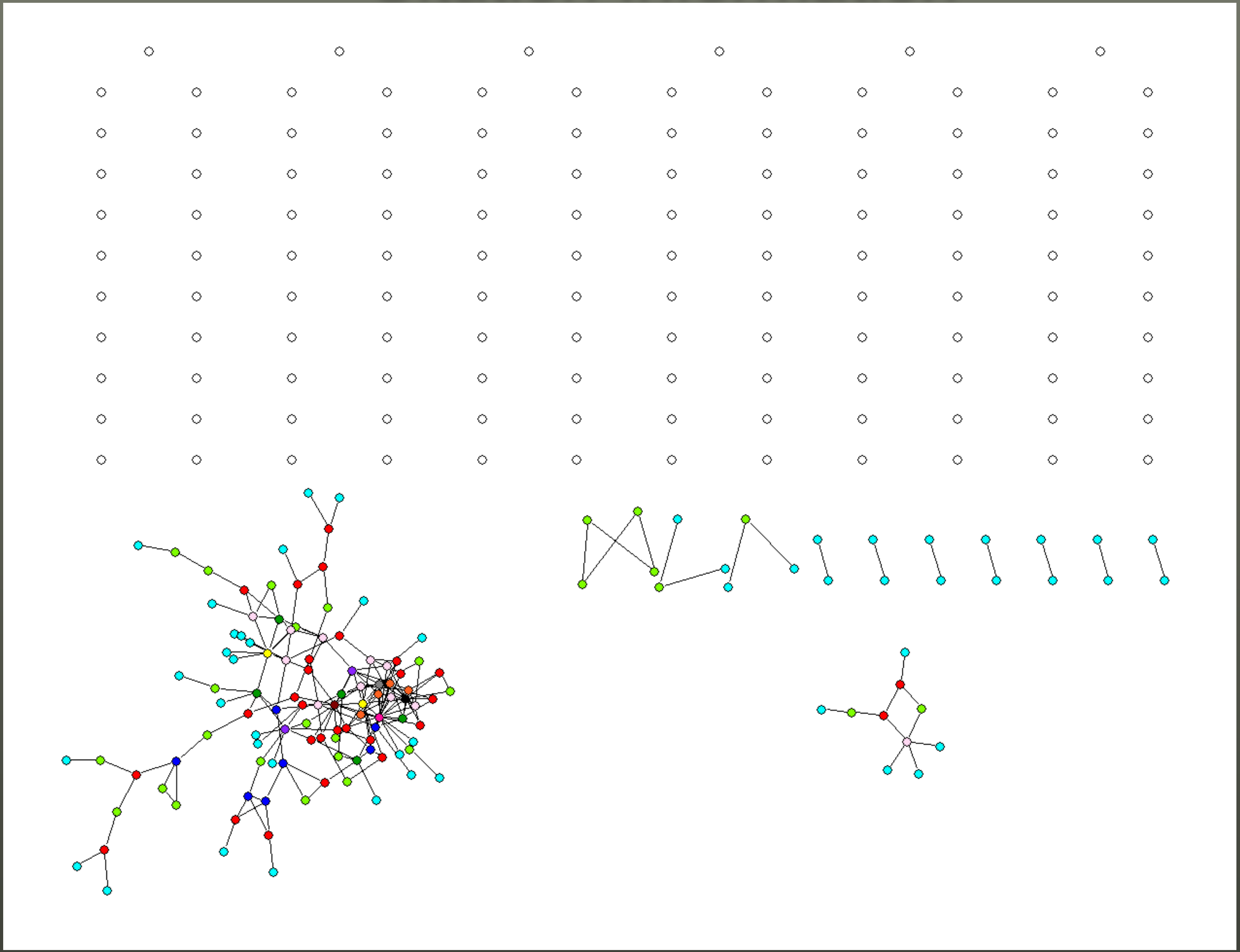
DEVELOPING
Shared Vision

Environment/Structures

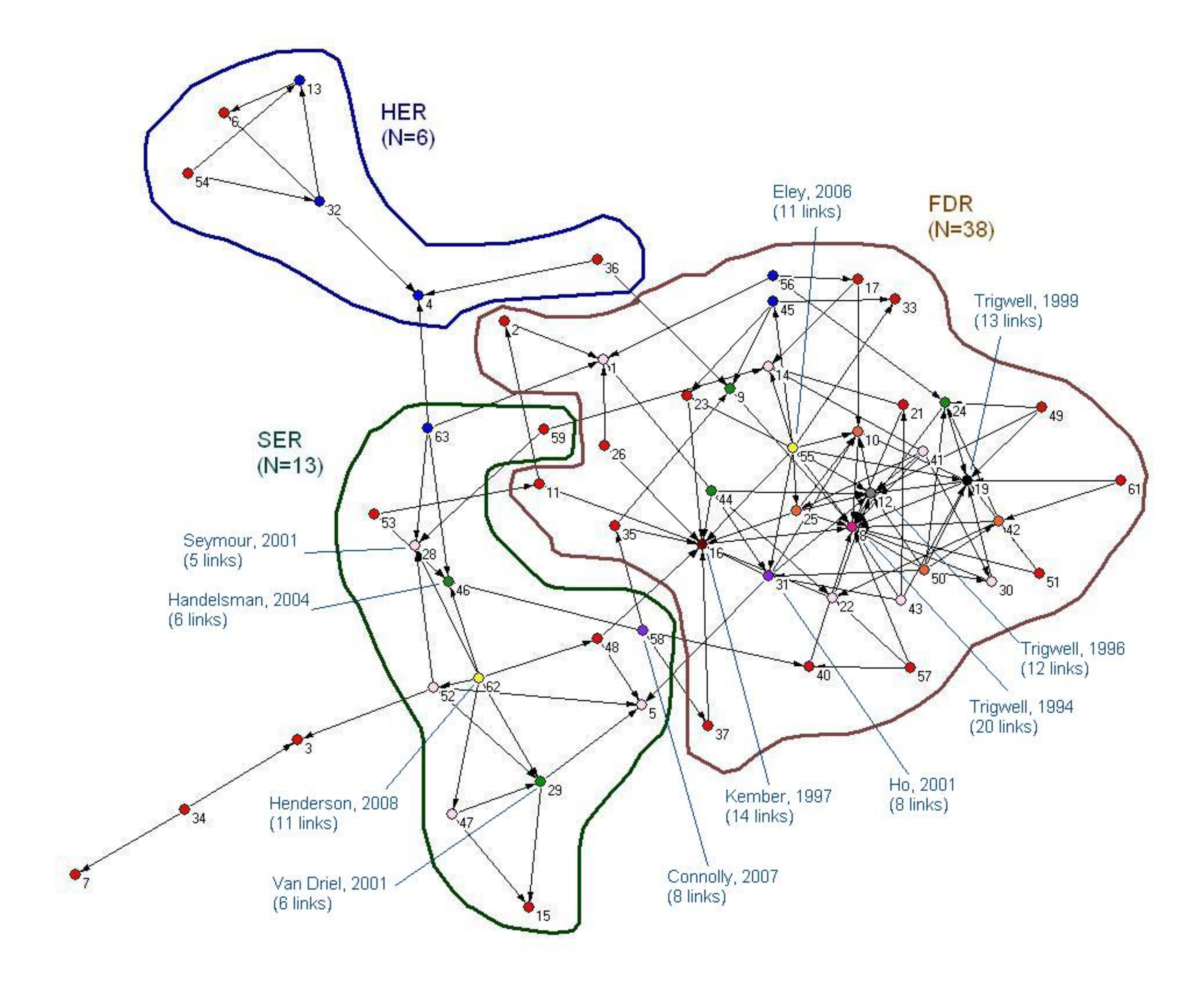
All 265 Articles with Complete Citation Information

126 articles (47%) have no links

50 articles (18%) have 1 link



Articles in the largest cluster with three or more links (N=57)



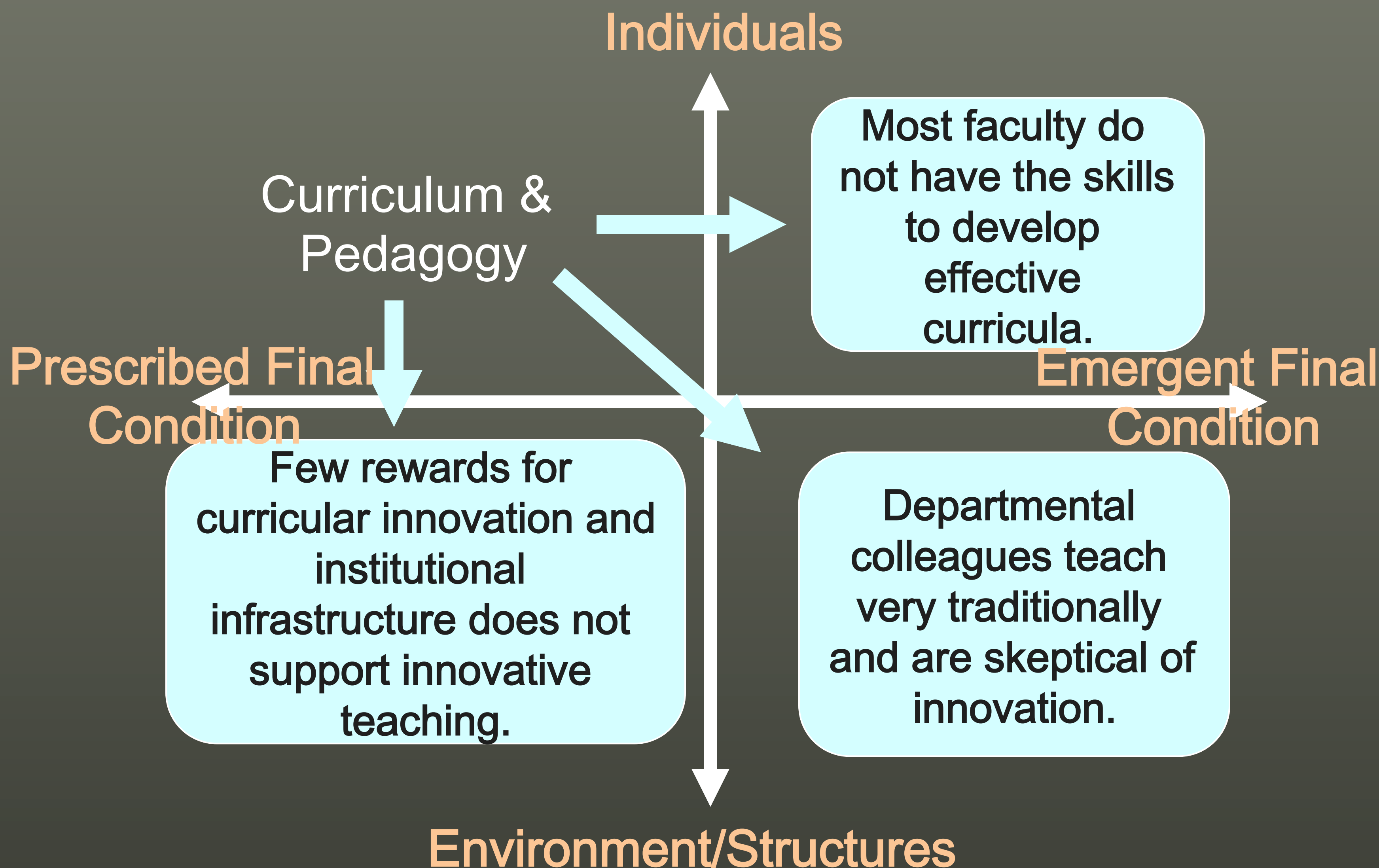
Three Isolated Research Communities

- Each has a different and important perspective.

- There is little interaction between groups and minimal interaction within groups

- (Based on a citation analysis of articles in the data set.)

Each change strategy sees areas of influence of other strategies as outside of their control



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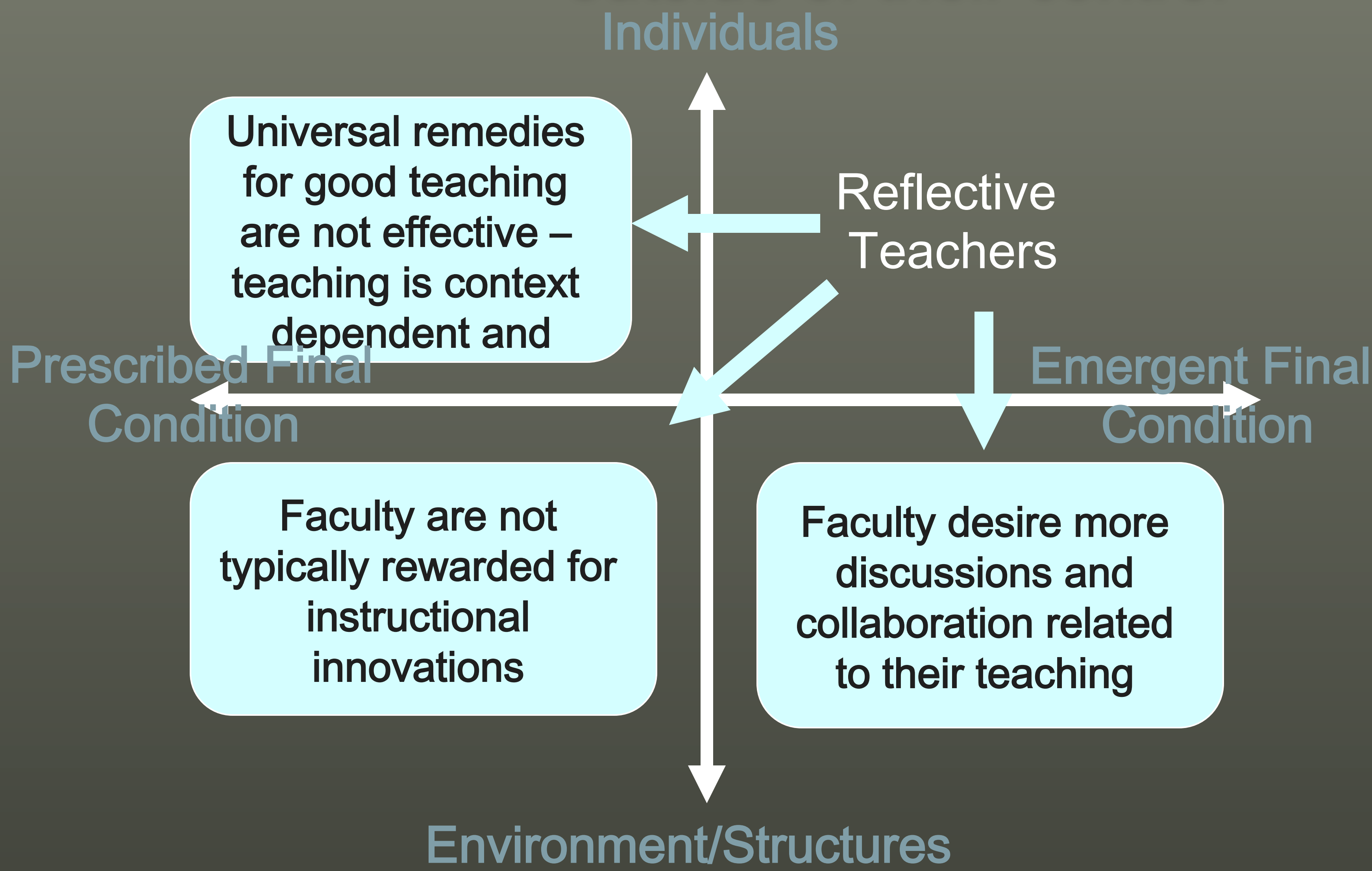

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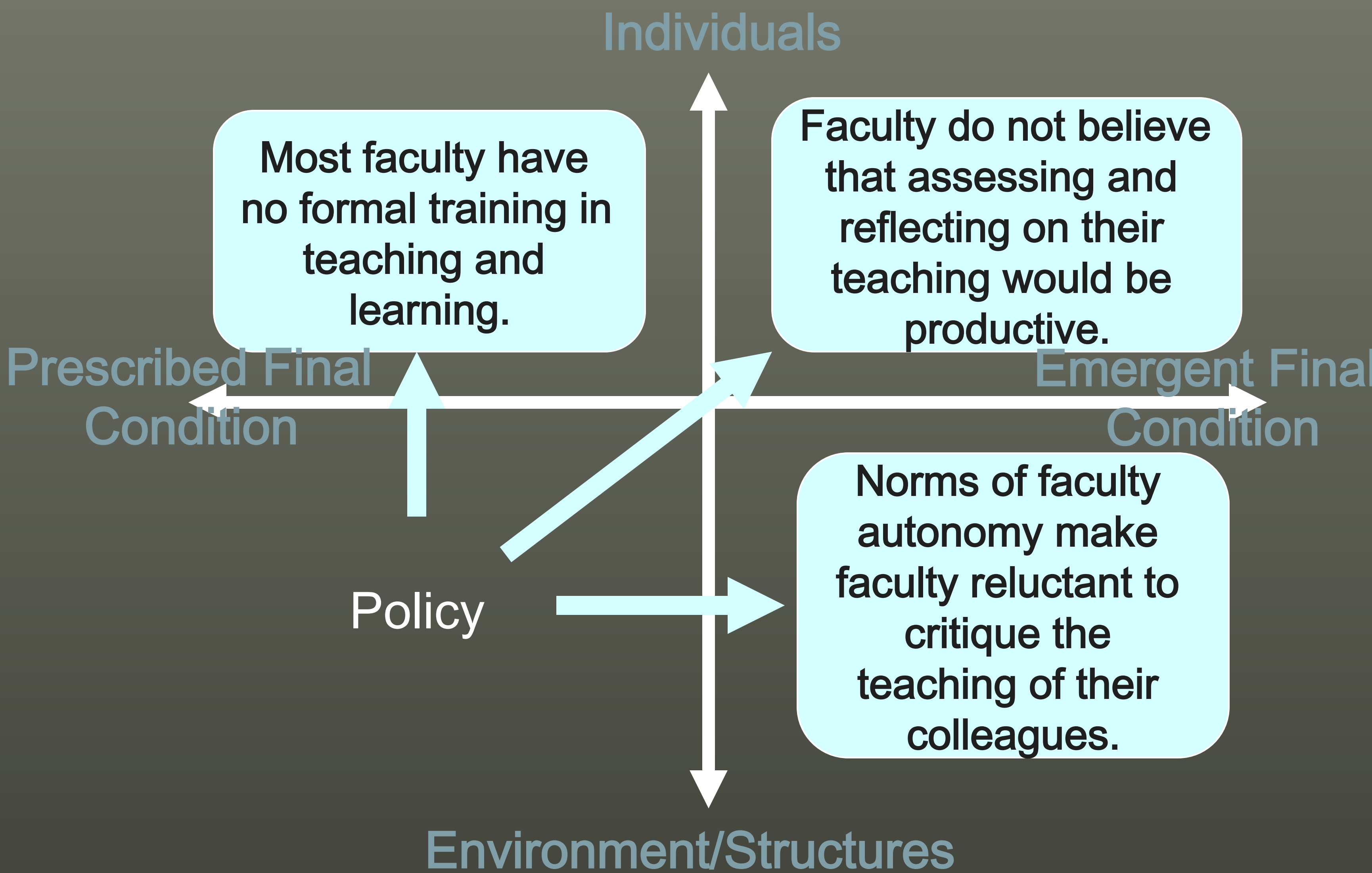
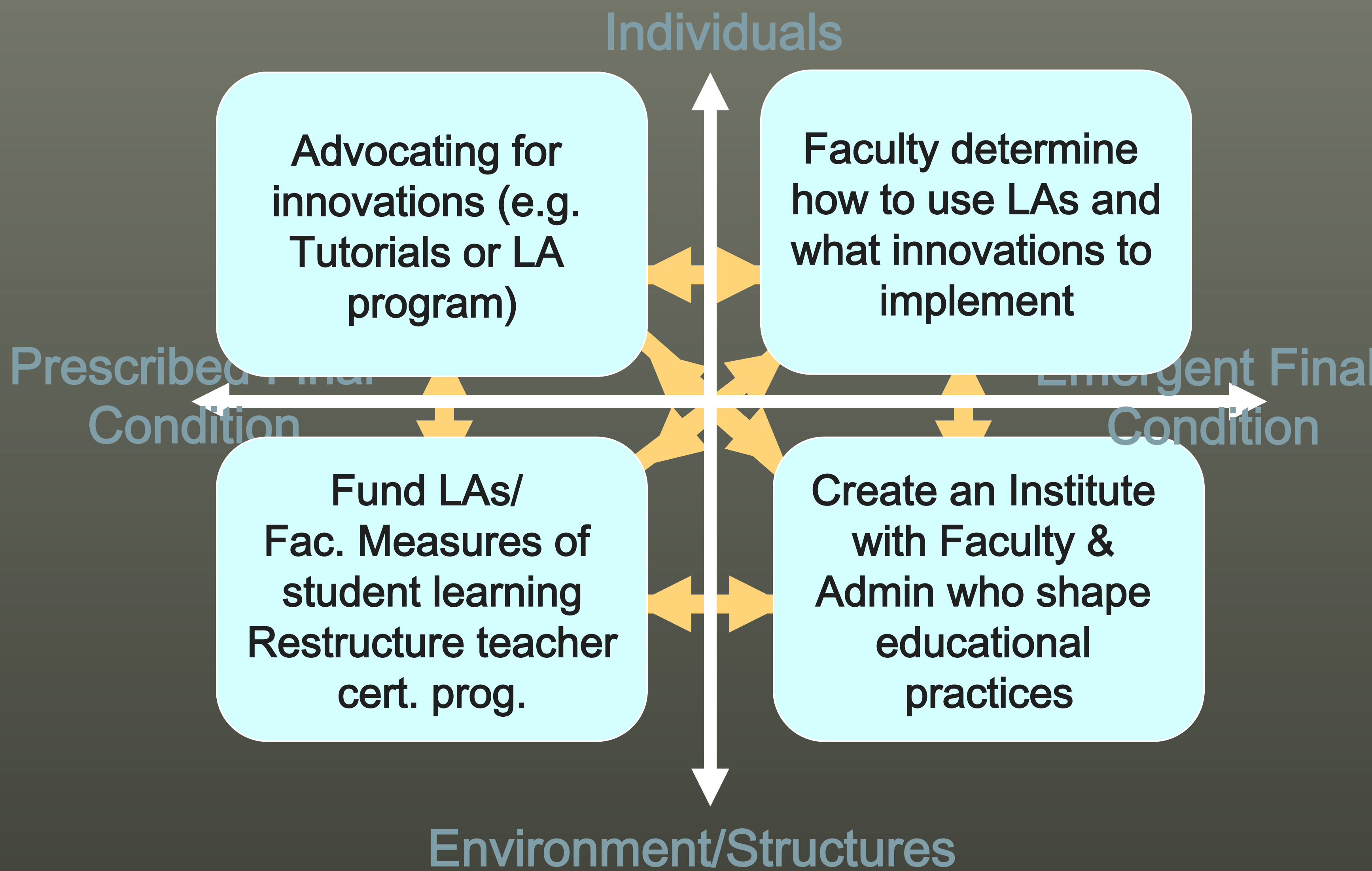


Revisiting Colorado's I3 Approach



Program Activities – Theoretical Foundations

Individuals

DEVELOPING
Curriculum &
Pedagogy

DEVELOPING
Reflective
Teachers

Prescribed Final Condition

Integrating STEM Education
UNIVERSITY OF COLORADO BOULDER

Emergent Final Condition

DEVELOPING
Policy

DEVELOPING
Shared Vision

Environment/Structures

Facilitating Change in
STEM
Undergraduate Education

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b. Course			
c. Depart'l	Faculty us based mater		dept'l s

Transforming Courses:
sion

Impacts of Faculty Variation

A Framework for models of STEM educational change

with Chandra Turpen (2010)

With SPollock, K. Perkins, H. Lewendowski, B. Zwickl

with P. Kohl (2007) and N. Podolefsky (2008)

with Andrea Beach & Charles Henderson

NSF 0448176, CAREER: Physics Education and Contexts of Student Learning.

Don’t Have a Standard Model But We do know about:

Student reasoning in physics

Student practices

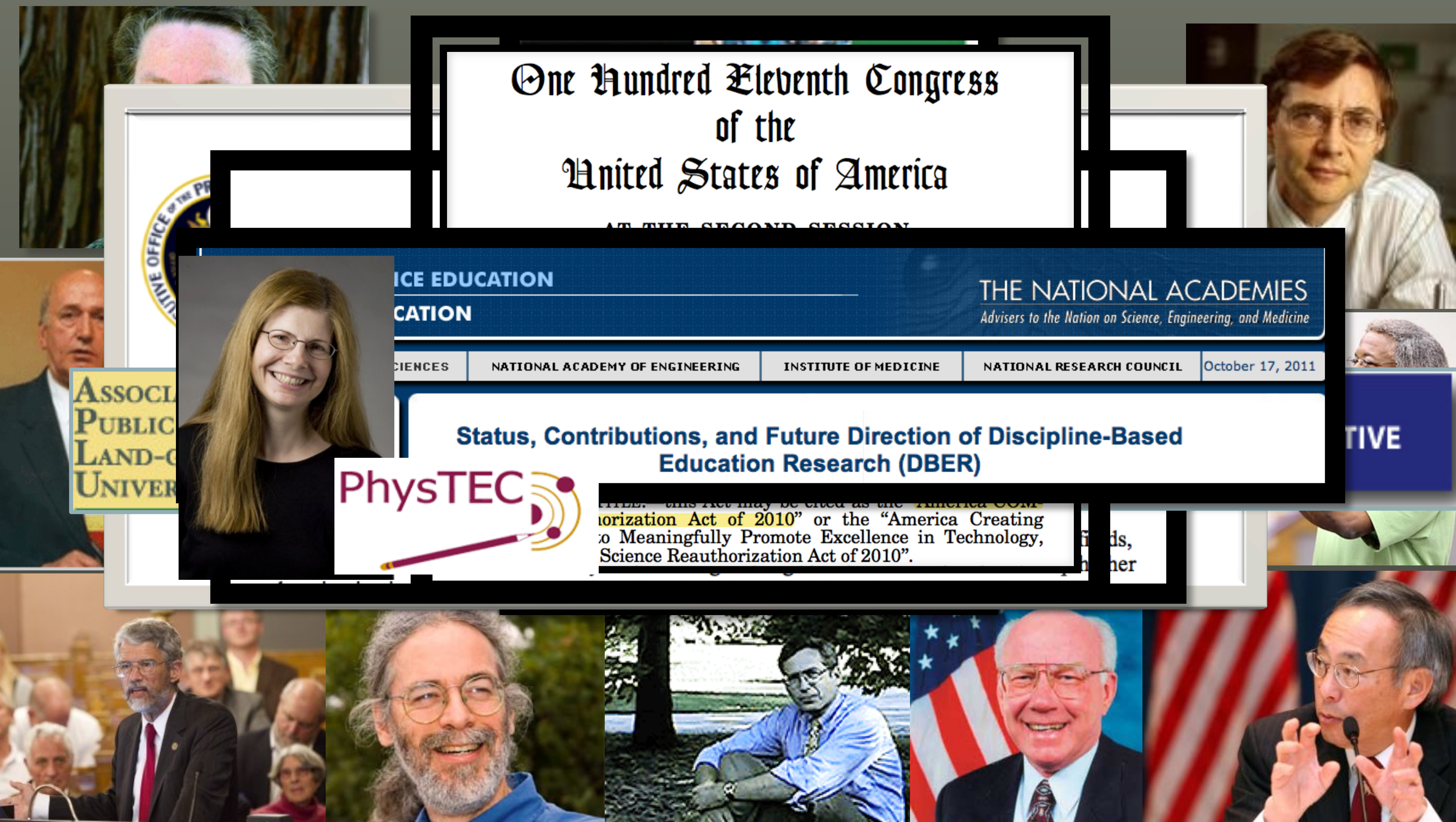
Faculty use of tools practices and norms

Course tools, practices, norms

Departmental tools, practices, norms

Institutional tools, practices, norms

I'm Proud that the Sciences identify with DBER and education



We are the ones involved where it matters most

We are the ones involved where it matters most and it's catching …

Physics Teacher Education Coalition

SMTI Science & Mathematics Teacher Imperative

131 A·P·L·U Universities Across 44 States Commit to the Science and Mathematics Teacher Imperative

(AS OF APRIL 20, 2012)

Fin

Much more at: *per.colorado.edu*