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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May Lee
Mike Ross
Ben Spike
Ben Van Dusen
Bethany Wilcox
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)
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?
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 undergraduate 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
High Education & Disciplines: a key lever in education
Physics Education Research
Course Transformation: Engagement in Learning

Students Attitudes and Beliefs: Selecting vs. Breeding Physics Majors

% Favorable CLASS score 1st Semester

PERC 2010, Perkins & Gratny
Designing Effective Simulations
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
Trad’I Model of Education

Individual → Instruction via transmission → Content (e.g. circuits)

transmissionist
Built in to our classes?
PER Theoretic Background

Individual

Instruction via transmission

Content (E/M)

Active construction

Individual

Prior knowledge

Content

transmissionist

constructivist
PER Theoretic Background

Instruction via transmission

Individual

Content (E/M)

Tools / Instructor . . .

Individual

Content (E/M)

Prior knowledge

Contextual constructivist

context

Attitudes and Beliefs

Student background

Affect


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
Theorem: If a moving particle, carried uniformly at constant speed, traverses two distances, then the time intervals required are to each other in the ratio of their distances.

A $2^{\text{nd}}$ Example

\[
\frac{7960.0}{10} = 796.0
\]

Easy!

\[
\frac{7960.0}{16} = \text{Hard(er)}
\]

\[
\frac{1F18.0}{10} = 1F1.8
\]

Decimal (Base 10)  Hex (Base 16)
Meaning of tools

Evolutionary (biological):

And cultural:

Physicists: $c \cdot r^2$

Mathematician: $c \cdot (r^2 + \theta^2)$

Thinking in terms of tools

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

Embedded Context(s)

Frames of Context

Departmental Level

Course (Physics I)

Class activity (Tutorial)

Task (2-D drawing)

Student

Concept

A broad perspective

- **i. Tools**
  - PhET simulations
  - Clickers & Tutorials

- **ii. Practices**

- **iii. Norms**
  - Student attitudes / beliefs

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- **a. Individ’l**
- **b. Course**
- **c. Depart’l**

---

## Foregrounding Context in PER

<table>
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<tr>
<td>a. Individ’l</td>
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<td>Representation Analogy, PhET</td>
<td>Tch to Lrn Physics Labs, Talking Physics</td>
<td>Class (beliefs) Interp in QM</td>
</tr>
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<td>b. Course</td>
<td></td>
<td>Sims in Class, Clickers in Class, Using Reps &amp; Analogy</td>
<td>Course Redesign, Clicker Use Tutorials</td>
<td>Tutorial Adaptation, Tchng Interpret., Gender intervention</td>
</tr>
<tr>
<td>c. Depart’l</td>
<td></td>
<td>Faculty use of PER, Frameworks of change</td>
<td>TA, PD, Fac Dvmt Community Partnr</td>
<td>Dept’l norms, Partnership in Phys Inclusion</td>
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**Sample applications**

- **Transforming Courses:**
  - Impacts of Faculty Variation in Peer Instruction
  - A Framework for models of STEM educational change

**Additional Information**

- NSF 0448176, CAREER: Physics Education and Contexts of Student Learning.
- with Andrea Beach & Charles Henderson
- With SPollock, K. Perkins, H. Lewendowski, B. Zwickl
## Sample applications

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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

Using Reps and Cueing

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*
SOLAR SYSTEM

- Planet revolves around sun
- Sun attracts planet
- Sun is yellow

ATOM

- Electrons
- Nucleus
- Confined to atom

Bohr Atom Blend

- Nucleus attracts electrons
- Orbits are energy levels

Adapted from Fauconnier & Turner (2002)
Analogical Scaffolding
Layering Blends to Make Meaning

$R_i = \text{Referents}$
$S_i = \text{Signs}$
$C_i = \text{Schemas}$
Apply to curriculum: teaching abstract concept

EM Wave
- 3D
- Transverse
- Field
- Propagating

Compile meaning into representation

The study

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

<table>
<thead>
<tr>
<th>Part I: Basic wave props</th>
<th>Analogy (N=72)</th>
<th>No-Analogy (N=74)</th>
</tr>
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<tr>
<td>Part II: Plane wave / 3D</td>
<td>String E/M</td>
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<td>Part III: E/M wave as field</td>
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(UW approach)

Pre / Post Assessment: rank time averaged signal at antennas
Results

Podolefsky, PRST – PER 2007
Results

Podolefsky, PRST – PER 2007
Another Study- Which Reps?

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

**Abstract**

Sine

**Blend**

Sine + Pictorial

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<td>(String)</td>
<td>(Sound)</td>
<td>(E/M)</td>
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Pre / Post Assessment: rank magnitude of E-field, free response

Adapted from UW *Tutorials*

The figure shows an electric field vector 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.
AS Model of Representations

Abstract

2D Wave

Sound wave

Up means up

EM wave

Up means up

Blend

3D Wave

Sound wave

2D Up means up

Wave is disturbance in density

Sound wave

3D

Wave is disturbance in density

EM wave

3D

Wave is disturbance

EM wave

3D

Wave is disturbance in field

EM wave

3D

Wave is disturbance in field
more at: per.colorado.edu/analogy
### Sample applications

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Impacts of Faculty Variation in *Peer Instruction* with Chandra Turpen (2010)
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

Leaves Stage

Answers Student Questions
Discusses with Students
Wrong Answer(s) Discussed
Student Explanation(s) heard
Different Opportunities for students

<table>
<thead>
<tr>
<th></th>
<th>Yellow</th>
<th>Green</th>
<th>Red</th>
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<tr>
<td>Apply new physical concepts</td>
<td><img src="image" alt="Yellow" /></td>
<td><img src="image" alt="Green" /></td>
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<td>🟢</td>
<td>🟠</td>
<td>🍊</td>
</tr>
<tr>
<td>Evaluate problem solutions</td>
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<td>🍊</td>
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</table>
**Norm: Faculty-student collaboration**

**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

**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

**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

Low collab.  |  High collab.
Q4: Awkward to ask professor questions
## Students Perceive Differences

<table>
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<td><strong>Q3:</strong> Comfort discussing</td>
<td></td>
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<tr>
<td><strong>Q5:</strong> Speak to Professor</td>
<td></td>
<td></td>
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<td><strong>Q6:</strong> Ask question</td>
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# Students Perceive Differences

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<td>Q3: Comfort discussing</td>
<td>p=0.03</td>
<td></td>
<td></td>
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<td>p&lt;0.001*</td>
<td></td>
<td></td>
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* Significant
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<td>R p&lt;0.001*</td>
<td>G p=0.02</td>
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* 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.
### Theme: Tools

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A Framework for models of STEM educational change

with Andrea Beach & Charles Henderson
Keeping the Good things Going: Study and Improvement of Change Strategies in STEM Education

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?
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?

<table>
<thead>
<tr>
<th>Individuals</th>
<th>Environments and Structures</th>
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<tbody>
<tr>
<td><strong>personal characteristics</strong> of single individuals, such as beliefs, knowledge, behaviors, etc.</td>
<td><strong>impact characteristics of the system</strong> such as rules, physical characteristics of the environment, norms, etc.</td>
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2. To what extent is the outcome prescribed in advance?

<table>
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<th>Prescribed Final State</th>
<th>Emergent Final State</th>
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<td>final state is known at the beginning of process</td>
<td>final state is developed</td>
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</table>
Each Strategy has a Unique Emphasis

- Individuals
- Environment/Structures

DEVELOPING
- Curriculum & Pedagogy
- Policy

Prescribed Final Condition

DEVELOPING
- Reflective Teachers
- Shared Vision

Emergent Final Condition

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.

- Individuals
  - Most faculty do not have the skills to develop effective curricula.
  - Departmental colleagues teach very traditionally and are skeptical of innovation.

- Curriculum & Pedagogy
  - Few rewards for curricular innovation and institutional infrastructure does not support innovative teaching.
Each change strategy sees areas of influence of other strategies as outside of their control.

Universal remedies for good teaching are not effective – teaching is context dependent and

Faculty are not typically rewarded for instructional innovations

Faculty desire more discussions and collaboration related to their teaching

Prescribed Final Condition

Emergent Final Condition

Individuals

Reflective Teachers

Environment/Structures
Each change strategy sees areas of influence of other strategies as outside of their control.

**Policy**

- Most faculty have no formal training in teaching and learning.

**Environment/Structures**

- Faculty do not believe that assessing and reflecting on their teaching would be productive.
- Norms of faculty autonomy make faculty reluctant to critique the teaching of their colleagues.

**Individuales**

- Faculty do not believe that assessing and reflecting on their teaching would be productive.

**Prescribed Final Condition**

- Most faculty have no formal training in teaching and learning.

**Emergent Final Condition**

- Norms of faculty autonomy make faculty reluctant to critique the teaching of their colleagues.
Revisiting Colorado’s I3 Approach

Prescribed Final Condition

Advocating for innovations (e.g. Tutorials or LA program)

Faculty determine how to use LAs and what innovations to implement

Fund LAs/ Fac. Measures of student learning Restructure teacher cert. prog.

Create an Institute with Faculty & Admin who shape educational practices

Emergent Final Condition

Individuals

Environment/Structures

Facilitating Change in STEM Undergraduate Education
Program Activities – Theoretical Foundations

- **Prescribed Final Condition**
- **DEVELOPING Policy**
- **Individuals**
  - Developing Curriculum & Pedagogy
  - Developing Reflective Teachers
  - Developing Shared Vision
- **Environment/Structures**
  - Integrating STEM Education
  - University of Colorado Boulder

- **Emergent Final Condition**

Facilitating Change in STEM Undergraduate Education
## Sample applications

<table>
<thead>
<tr>
<th>Theme</th>
<th>i. Tools</th>
<th>ii. Practices</th>
<th>iii. Norms</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Indiv'l</td>
<td>Representation &amp; Analogy; Use in the Classroom</td>
<td>Learning by teaching</td>
<td>CLASS-Student attitudes and beliefs (ABs)</td>
</tr>
<tr>
<td>b. Course</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Depart'l</td>
<td>Faculty use of PER-based materials</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Transforming Courses:**

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 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 ...