Physics Education Research in the Advanced Undergraduate Classroom

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4 October 2013

Outline

• Short background on introductory course transformations at CU Boulder:
  – Interactive engagement and peer instruction
  – Trad. HW sessions replaced by small group work

• Transforming advanced courses:
  – Model for course transformation
  – Interactive engagement in advanced classrooms
  – How do we know it’s working?
  – Is this relevant to St Andrews?

Traditional model of teaching:
"transmitting knowledge"

A Wakeup Call

Force Concept Inventory (FCI) *

• 30 questions
• Basic Newtonian concepts.
• Research-based

Hestenes, Wells, Swackhamer, Physics Teacher 29, 141 1992

FCI – Sample Question

Looking down at a track (flat on table), a ball enters at point 1 & exits at point 2. Which path does it follow? (neglect all friction)

Force Concept Inventory

Take home message:

Students learn less than 25% of the most basic concepts (that they don’t already know).


Personal Response Systems

Consider this glass tube full of atoms, discharge lamp

Expect that on average
a. more photons will come out right hand end of tube
b. less come out right
c. same number as go in
d. none will come out.


S. Pollock and N. Finkelstein, PRST-PER. 4, 010110 (2008)

Traditional Classroom

Reconceptualise the learning environment:
- learning materials
- classroom format
- role of instructor

Collaborative Learning
Advanced UG Physics Students – BEMA Scores

Long Term Impacts

F04-F05
S06-S07
Semester in advanced UG E&M

Students with no Wash. Tutorials in introductory E&M

S. Pollock, PRST-PER 5, 020101 (2009)

F04-F05
S06-S07
Semester in advanced UG E&M

Had introductory E&M with Wash. Tutorials

S. Pollock, PRST-PER 5, 020101 (2009)

Can physics majors learn better from interactive techniques adapted from introductory physics classrooms?

Typical Lecture Course

Students debate a concept test

Model for Course Transformation

What should students learn?

Establish learning goals

Mechanics & Math Methods
Electromagnetism
Quantum Mechanics
Advanced Lab

Apply research-based teaching techniques. Measure progress!

Which instructional approaches improve student learning?

Using Research & Assessment

What are students learning?

Model for Course Transformation

What should students learn?

Establish learning goals

What are students learning?

Which instructional approaches improve student learning?

Advanced Lab
Course Learning Goals

- From faculty working group
- Framed course transformations
- Made explicit to students

Students should be able to...

...calculate and sketch the direction of the dipole moment of a given charge distribution.

...outline the general steps necessary for solving a problem using separation of variables.

Course Learning Goals

- From faculty working group
- Framed course transformations
- Made explicit to students

Students should be able to...

...achieve physical insight through the mathematics of a problem

...choose and correctly apply the appropriate problem-solving technique

Model for Course Transformation

Apply research-based teaching techniques.

Measure progress!

STEMclickers.colorado.edu

Arguments against clicker use

- Eats up time
  *Important ideas in lecture, continue learning in HW*
- Discussion easy in small classes
  *We/they don’t always know they need to ask questions*
- Students are sophisticated learners
  *Clickers can augment traditional learning*
- Students may resist
  *But perhaps only initially…*
- Extra effort for instructors
  *Question banks available if you want to try!

Students find clickers useful

Q: How useful for your learning is the addition of clicker questions compared to pure lecture with no clicker questions?

- Lecture with clickers much more useful
- Lecture with clickers more useful
- Same
- Pure lecture more useful
- Pure lecture much more useful

78% of students

12 courses, 264 student responses

Students don’t predict their usefulness

Q: Would you recommend using clicker questions in upper-level physics courses?

<table>
<thead>
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<th>Highly Recommended</th>
<th>Recommended</th>
<th>Neutral</th>
<th>Not recommended</th>
<th>Definitely not recommended</th>
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Which of the following could represent an electrostatic field in the region shown?

I

II

A) Both
B) Only I
C) Only II
D) Neither

Silent voting: about 65% correct
After discussion: over 95% correct

Consider this 3D vector field in spherical coordinates:

$$\vec{V}(r) = c\left(\frac{\hat{r}}{r^2}\right)$$

The divergence of this vector field is:

A) Zero everywhere except at the origin
B) Zero everywhere including the origin
C) Non-zero everywhere, including the origin.
D) Non-zero everywhere, except at origin (zero at origin)
E) Not sure how to get this without computing $\text{Div} \cdot \vec{V}$

Model for Course Transformation

Data Sources
- Classroom observations & student work
- Student interviews
- Attitude surveys
- Traditional exams
- End-of-course conceptual assessments

Research-Validated Assessments
- Electrostatics: Colorado Upper-division Electrostatics Assessment (CUE)
- Electrodynamics: Colorado Upper-division Electrodynamics Test (CURient)
- Classical Mechanics: Colorado Classical Mech/Math Methods Instrument (CCMI)
- Quantum Mechanics: Quantum Mechanics Assessment Tool (QMAT)
- Advanced Lab: Colorado Learning Attitudes about Science Survey for Experimental Physics (E-CLASS)
The document contains various sections of text, diagrams, and tables. Here is a formatted version:

**CUE Assessment**

Do not solve, but give “the easiest method you would use to solve the problem” & “why you chose that method”.

33% of students did not recognize Gauss’ law as the easiest way to solve. (N=325)

\[ \rho(r) = \rho_0 e^{-r^2/a^2} \]

24% of students incorrectly chose Gauss’ law as the easiest way to solve. (N=325)

**Exam Results by Learning Goal**

- Calculation
- Reasoning
- Expectation
- Method 1 (Gauss)
- Method 2 (Ampere)

**Average CURrent Total Scores**

\[ \oint \mathbf{X} \cdot d\mathbf{a} = \iint \mathbf{X} \cdot d\mathbf{a} \]

\[ \mathbf{X} = \nabla \times \mathbf{Y} \]

\[ \rightarrow \iint \mathbf{X} \cdot d\mathbf{a} = \iint (\nabla \times \mathbf{Y}) \cdot d\mathbf{a} = \oint \mathbf{Y} \cdot d\mathbf{l} \]

62% completely correct, overall average = 71%
4. A steady current flows in a wire. The diagram depicts the current density $\mathbf{J}$ inside a section where the diameter of the wire is gradually decreasing.

Inside this section of wire, is the divergence of the current density $\nabla \cdot \mathbf{J}$ zero or non-zero? Briefly explain your reasoning.

$$\nabla \cdot \mathbf{J} = -\frac{\partial \rho}{\partial t}$$

34% correct answer, 29% correct reasoning

5. Is the electromagnetic energy density increasing, decreasing or remaining constant?

Is the total flux of the Poynting vector $\mathbf{S}$ positive, negative or zero? (the area vector points outwards)

~ 2/3 correct

~ 1/3 correct

www.colorado.edu/sei/physics/

- Materials for instruction and evaluation
  - Clicker Questions
  - Tutorial-style Activities
  - Homework and Exam questions
  - End-of-course assessments

- Resources for instructors
  - User’s guides
  - Documentation of observed student difficulties

Modern Physics, Classical Mechanics/Math Methods
Electromagnetism, Quantum Mechanics, Advanced Lab

Questions?

http://per.colorado.edu

www.colorado.edu/sei/physics/

Clicker videos at
STEMclickers.colorado.edu