A research-based approach to transforming upper-division E&M

Steven Pollock
+ Kathy Perkins
+ Stephanie V. Chasteen
+ Rachel Pepper

Physics Dept. and Science Education Initiative
University of Colorado at Boulder
CU Physics Education Research

Physics faculty:
Michael Dubson
Noah Finkelstein
Kathy Perkins*
Steve Pollock
Carl Wieman*

*Science Education Initiative
Wendy Adams
Noah Podolefsky
And 12 Teaching Fellows in 5 departments

Ph. D. students:
Lauren Kost
Chandra Turpen
Ben Spike
Charles Bailey

Postdocs:
Stephanie Chasteen*
Steven Goldhaber*
Rachel Pepper*

Non-PER participating faculty
Paul Beale (chair)*
Edward Kinney
Oliver DeWolfe
+ working groups

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CU Integrating STEM
Why Transform E&M I?

Lecture with clickers

Washington Tutorials

Can our majors learn better from interactive techniques adapted from introductory physics?
What Changed?

- Faculty collaboration
- Explicit learning goals
- Interactive classroom techniques
- Concept Tests

- Modified Homework
- Homework Help Sessions
- Tutorials

Students debate a concept test
What’s special about upper-div?

- Intellectually more sophisticated students
- Faculty and student investment & identity
- Complex physics
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

... be able to choose and apply the appropriate problem-solving technique

... demonstrate intellectual maturity
Did it Work? Assessments

- Compared **Traditional** (3 courses) & **Transformed** (4 courses) at CU and elsewhere (N=220).

- Attendance and reported time on homework

- Common **traditional exam questions** (5)

- Developed **Colorado Upper-Division Electrostatics Assessment (CUE)** to gauge progress on learning goals
  - High internal statistical consistency, high inter-rater reliability
Results: CUE and Trad’l Exams

Students in 4 semesters of Transformations at CU and elsewhere performed significantly better ($p<0.05$) on all measures.

N=220
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
- more useful
- same
- more useful
- much more useful

Upper-div courses using clickers:
- 12 courses, 264 student responses

79% of students

Upper-Level Course Transformation
Univ. of Colorado
Q: Would you recommend using clicker questions in upper-level physics courses?

- In highly rated pure lecture, No clickers (QM II, n=17)
- Add Clickers (QM I, n=30)
- Missing clickers? (EM II, n=16)
Students’ recommendation for implementation

# of Qs per lecture: 2-5 [2-3 (62%); 4-5+ (21%)]

Timing: Interspersed with lecture (87%)

Peer-discussion: Allow and encourage (80%)

Preferred response mode:
  93% prefer peer discussion as part of response
  64% prefer some time for individual thinking prior to peer discussion

N=11 courses, 224 responses
Whiteboard activities

• 1X week
• Uncertain impact

• Uses:
  – Sketch a function (wavefunction or E-field)
  – Concept map of physics
  – Work out an integral or other computation
Concept map (whiteboard)

- Math
- Classical Mechanics
- Research
- Quantum Stuff
- Thermo Stuff
- E&M
- Chemistry

- Being able to talk to other people
J-B-A triangle (whiteboard)
Boundary conditions for D/E

\[ \frac{\tan \theta_1}{\tan \theta_2} = \frac{E_1}{E_2}, \quad \frac{E_1}{E_1'} = \tan \theta_1, \quad \frac{E_2}{E_2'} = \tan \theta_2 \]

\[ \frac{E_1''}{E_1'} = \frac{E_2}{E_2'} = \frac{E_2 \cos \theta_2}{E_1 \cos \theta_1} = \frac{D_2 \cos \theta_2}{D_1 \cos \theta_1} \]

\[ \tan \theta_1 = \frac{E_1}{E_2}, \quad \tan \theta_2 = \frac{E_2}{E_1} \]
Kinesthetic activity

Largely built on OSU (Paradigms) materials

- You are all positively charged.
- Picture the E-field as you enter
- What external work is needed to get to your seat?
Concept Tests

- Allowed students to **discuss & debate** challenging, high-level ideas

An ideal (large) capacitor has charge Q. A neutral *linear* dielectric is inserted into the gap (with given dielectric constant)

**Where is D discontinuous?**

- +Q
- -Q

i) near the free charges on the plates
ii) near the bound charges on the dielectric surface

A) i only  B) ii only  C) i and ii ONLY  D) i and ii but also other places  E) none of these/other

Which of the following *could* be a static physical E-field in a small region?

- [Diagram of field options]

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

- [Bar charts showing student responses]

[Image of idclicker]
Homework

- Traditional HW problems were modified
- Sense-making, real-world context, estimations, and more.

**Q2. DIVERGENCE AND CURL**
Consider a field $E = c \frac{\vec{r}}{r^2}$ (which is NOT the field from a point charge at the origin, right?!)

a) **Sketch it.** Calculate the divergence *and* the curl of this $E$ field. Test your answers by using the divergence theorem and Stoke's theorem. *Is there a delta function at the origin like there was for a point charge field, or not?*

b) **What charge distribution would you need to produce an E field like this?** Describe it in words as well as formulas. (Is it physically realizable?)

Sample HW problem aligned with learning goals. Non-traditional portions in bold.
Tutorials & HW Help Sessions

Optional help sessions (2) and tutorials (1) each week

Part 1 – Conceptually Understanding Conductors

A coax cable is essentially one long conducting cylinder surrounded by a conducting cylindrical shell. Draw the charge distribution (little + and – signs) if the inner conductor has a total charge +Q on it, and the outer conductor has a total charge –Q. Be precise about exactly where the charge will be on these conductors, and how you know.
Example Questions

• Conceptual
• Math/Physics connection
• Application of ideas
• Step in calculation, proof, derivation
Questions: Fundamentals

We have a large copper plate with uniform surface charge density $\sigma$. Imagine the Gaussian surface drawn below. Calculate the E-field a small distance $s$ above the conductor surface.

A) $|E| = \sigma/\varepsilon_0$
B) $|E| = \sigma/2\varepsilon_0$
C) $|E| = \sigma/4\varepsilon_0$
D) $|E| = (1/4\pi\varepsilon_0)(\sigma/s^2)$
E) $|E| = 0$

30% correct (60% voting “C”) before discussion - then 60% correct

Given a pair of very large, flat, conducting capacitor plates with surface charge densities $\pm \sigma$, what is the E field in the region between the plates?

A) $\sigma/2\varepsilon_0$
B) $\sigma/\varepsilon_0$
C) $2\sigma/\varepsilon_0$
D) $4\sigma/\varepsilon_0$
E) Something else

Freshmen: 45%, 60% next day
UD: 60% correct
**Questions: Conceptual**

5.17 If the arrows represent a B field (note that |B| is the same everywhere), is there a nonzero \( \mathbf{J} \) (perpendicular to the page) in the dashed region?

- A. Yes
- B. No
- C. Need more information to decide

\[ \vec{B} = B_0 \hat{\phi} \]

74% correct
(“Need more info”)

2.28 A point charge \( Q \) is placed outside a uniformly charged shell of charge (uniform \( \sigma \)).

What is the electric field inside the sphere?

- A: 0 everywhere inside
- B: non-zero everywhere in the sphere
- C: Something else
- D: Not enough info given

freshmen: 33%
ud: 80% correct
Questions: “Next step”

- Next step
  - Derivation
  - Proof
  - Calculation

84% correct

Part of generalized uncertainty principle proof in QM
Questions: “Application”

• Application
  – Of abstract idea
  – To new situation
  – To real-world
  – Variations on a theme

5.8 A "ribbon" (width a) of surface current flows (with surface current density K)
Right next to it is a second identical ribbon of current.
Viewed collectively, what is the new total surface current density?

A) K
B) 2K
C) K/2
D) Something else

5.14 What is B at the point shown?

A) \( \frac{\mu_0 I}{\pi s} \)
B) \( \frac{\mu_0 I}{2\pi s} \)
C) \( \frac{\mu_0 I}{4\pi s} \)
D) \( \frac{\mu_0 I}{8\pi s} \)
E) None of these

Mostly correct, but good discussions
Questions: Math/Physics

- Math/Physics
  - Apply mathematics to a physical situation
  - Translate physical situation into math

The voltage is constant everywhere along a line in space.

You can conclude that:
A) The E-field has constant magnitude along that line.
B) The E-field is zero along that line.
C) You can conclude nothing at all about the magnitude of E along that line.

Understanding
E=-(grad)V
Research on student difficulties

Research-based
- Tutorials
- Clicker Questions
- Homeworks
- Class activities

Research-validated
- Consensus learning goals
- CUE instrument
- Interviews and class observations

reflective
development
# Research on student difficulties

<table>
<thead>
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*reflective development*

**and next:**

• pre/post Tutorial assessments
Week 4 puzzler

Please type your name in the form: Last, First:

• collaboration w. UW
• weekly online pre-tests
• followup post-tests before exams
• investigate student difficulties and reasoning
In a bank heist gone awry, you and a friend are stuck inside a (conducting) metal bank vault. Somewhere completely inside the solid metal door is a lock-release mechanism that will trip if you drill through it. This mechanism is a positively charged insulator. Can you and your friend figure out the right place to drill by measuring the E-field inside the safe? Please explain your reasoning.

80%

Can your third accomplice, who is outside the safe, figure out where to drill by measuring the electric field outside the safe? Please explain your reasoning

50%
Which of the following could be a physically allowable static charge distribution?
Why/why not?

(a)  
(b)  
(c)  
(d)  
(e)  
(f)  

20%
1st posttests just in

By end of term:

• first round for all weeks
• some student interviews likely
• use results to re-write next round and inform Tutorial development
Summary

We are transforming an upper division class:
- Impact on content learning
- Impact on participation

Included faculty (buy-in?)

Developing materials and resources

Developing assessment instruments
### Upper-div Clickers at CU

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<th>Course</th>
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- ⭐: 12 non-PER faculty
- ⭐⭐: 2 PER faculty

UBC 09

Upper-Level Course Transformation

Univ. of Colorado

▶ 12 non-PER ★★ and 2 PER★☆ faculty
Questions?

• PER course materials for Quantum and E&M
  http://www.colorado.edu/sei/departments/physics.htm

  • Clicker videos and today’s talk at
    STEMclickers.colorado.edu

  http://per.colorado.edu