Thinking like a Physicist: Transforming Junior E&M

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Overview

We adapt **research-based techniques** known to be effective at the introductory level as proof-of-concept in how an upper-division course may be transformed in order to improve student learning[1]. Multiple **assessments** were used to evaluate effectiveness. The transformations have been used for **3 semesters** at CU.

All course materials are available online at www.colorado.edu/sei/departments/physics_3310.htm

Why Upper-Division E&M?

Electricity & Magnetism:

- Is a core course valued by faculty
- Requires sophisticated problem-solving
- Is often taught using traditional lecture and abstract formalism
- Has canonical content

E&M defines what it *means* to learn physics as a major.

Faculty Input

This project combined the skills of two typically non-overlapping groups:

- Faculty teaching introductory courses using methods of active engagement
- Faculty teaching upper-division courses using traditional lecture
- Working group of ~10 faculty met biweekly

Faculty involvement should increase **sustainability of changes** and alignment with **faculty values.**

Learning Goals

Content is canonical: Griffiths[2] Chapter 1-6. Ten broad learning goals were developed by faculty, such as

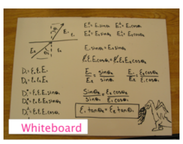
Students should be able to ... achieve physical insight through the mathematics of a problem
... choose and apply the appropriate problem-solving technique
... justify and explain their thinking and approach to a problem.

Learning goals drove the course transformations and assessments

The Transformations

Classroom Techniques

- ✓ **Interactive** lecture style
- ✓ Clicker questions and **peer discussion**
- ✓ Illustrative **simulations and demonstrations**
- ✓ **Kinesthetic activities**
- ✓ Student work on **small whiteboards.**



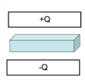
Concept Tests (clickers)

- ✓ 2-3 **challenging questions** in each 50-min class
- ✓ Allowed us to gauge student understanding
- ✓ Asked student to expand or apply lecture topics
- ✓ **Kept students engaged and following lecture**
- ✓ **Prepared students to learn from lecture**

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

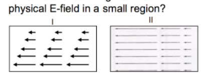
Where is D discontinuous?

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?



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

The SEI has compiled a guide to best practices in clickers[2]

Homework

In order to more explicitly target learning goals, we **modified traditional homework.**

For example, we added:

- ✓ Real-world contexts
- ✓ Articulating expected answer
- ✓ Making sense of final answer
- ✓ Approximations, expansions, estimations…

Q2. DIVERGENCE AND CURL

Consider a field $\mathbf{E} = c\frac{\vec{\mathbf{r}}}{r^2}$ (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 are the units of c? **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 aligned with learning goals. Non-traditional portions in bold.

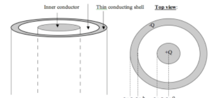
Tutorials

- 10 weekly tutorials w/ 3 semesters of development*
- Optional co-seminar (50-60% attendance)
- Socratic guided inquiry
- Run with assistance of undergrad Learning Asst[4].
- In addition to twice weekly HW help sessions

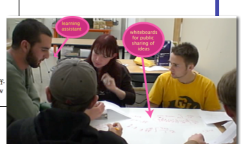
Prepared students for next homework by helping them conceptually interpret the mathematics

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.



Consider how the charge distribution would change if the inner conductor is shifted off-center, but still has +Q on it, and the outer conductor remains electrically neutral. Draw the new charge distribution (little + and – signs) and be precise about how you know.



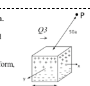
* Inspired by: OSU "Paradigms,"[5] "Griffiths by Inquiry,"[6] U. Washington Tutorials.[7]

Assessments

CONCEPTUAL ASSESSMENT

- **The CUE**[1] was developed to measure students' progress on learning goals. 17 short-answer questions.
- Developed to be **valid and reliable** using student interviews, faculty review, inter-rater reliability, and statistical evaluation of results (Cronbach $\alpha = 0.82$).
- The CUE was given to 226 students at CU and elsewhere. **All courses using the transformed materials scored higher on the CUE than other courses.**

Q3. Give a brief outline of the EASIEST method that you would use to solve the problem. *Do not solve the problem, we just want to know the general strategy and why you chose that method.* A solid, neutral non-conducting cube, centered on the origin, with side length "a" and charge density $\rho(z) = kz$, Find E (or V) outside, at point P, off-axis, at a distance r=50a.

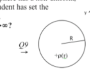


Q9. You are given a non-conducting sphere, centered at the origin. The sphere has a non-uniform, positive and finite volume charge density $\rho(r)$. You notice that another student has set the reference point for V such that V=0 at the center of the sphere: $V(r=0)=0$.

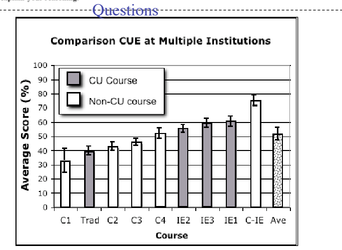
What would V=0 at r=0 imply about the sign of the potential at r→∞?

(a) V (r→∞) is positive (+)
(b) V (r→∞) is negative (-)
(c) V (r→∞) is zero
(d) It depends

Briefly explain your reasoning:



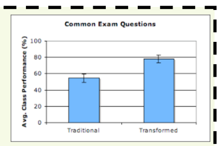
2 CUE Questions



Trad = traditionally taught course at CU; **IE1-3** = transformed courses at CU; **C-IE** = transformed course at private liberal arts college; **C1-4** = primarily lecture-based courses at other univs.

TRADITIONAL ASSESSMENTS

Students in a transformed course (IE1) performed better on 5 traditional exam problems given in common with a lecture based course (Trad).



Results & Conclusions

- We have transformed junior-level E&M to be more closely aligned with principles of how people learn, using the results of student observations and faculty input
- Compared to a traditional lecture, **students scored higher on traditional and conceptual assessments** and were **very enthusiastic about the course**.
- Students appreciate upper division clicker use, according to surveys in multiple courses

Pedagogical techniques that improve learning in introductory classes can have similar benefits in upper-division, resulting in improved learning for future physicists, teachers and engineers.

References & Acknowledgements

[1] S.V. Chasteen and S.J. Pollock *PERC Proc. 1064*, AIP, Syracuse, NY, 2008, p 91-94 and S. V. Chasteen and S. J. Pollock, *PERC Proceedings 2009*, submitted.
[2] D.J. Griffiths, Introduction to Electrodynamics, 3rd Ed. Upper Saddle River, New Jersey: Prentice Hall, 1999.
[3] http://www.colorado.edu/sei/fac-resources/guide.html
[4] http://stem.colorado.edu/la-program
[5] C. Manogue et al, Paradigms in Physics: A New Upper Division Curriculum, *Am.J.Phys*. **69,** 978-990 (2001). Curricular materials online at www.physics.oregonstate.edu/portfolioswiki.
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[7] L. McDermott, P. Shaffer, and the PEG *"Tutorials in Introductory Physics,"* Prentice Hall, 2002.

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