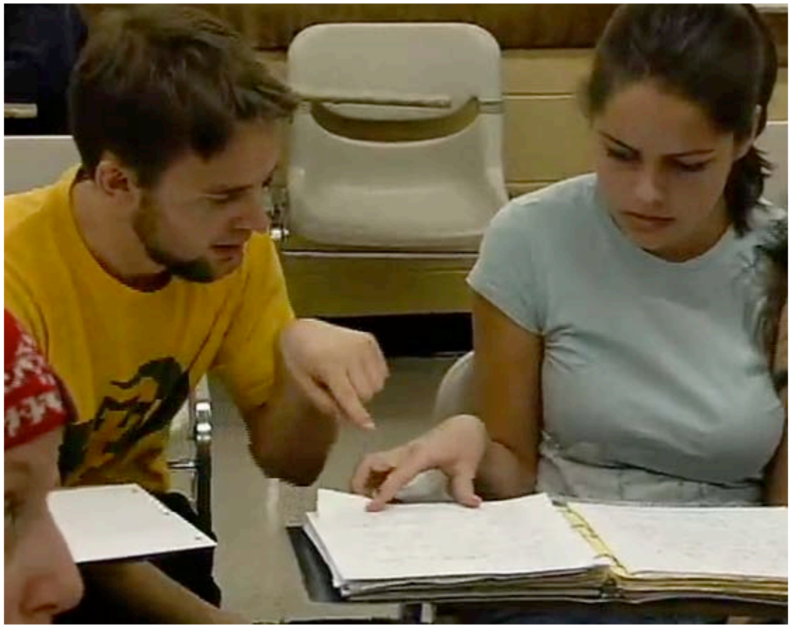
A research-based approach to transforming upper-division E&M

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

Project in part supported by CU *Integrating STEM*

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

Why Transform E&M I?

Lecture with clickers

Washington Tutorials

?

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

What Changed?

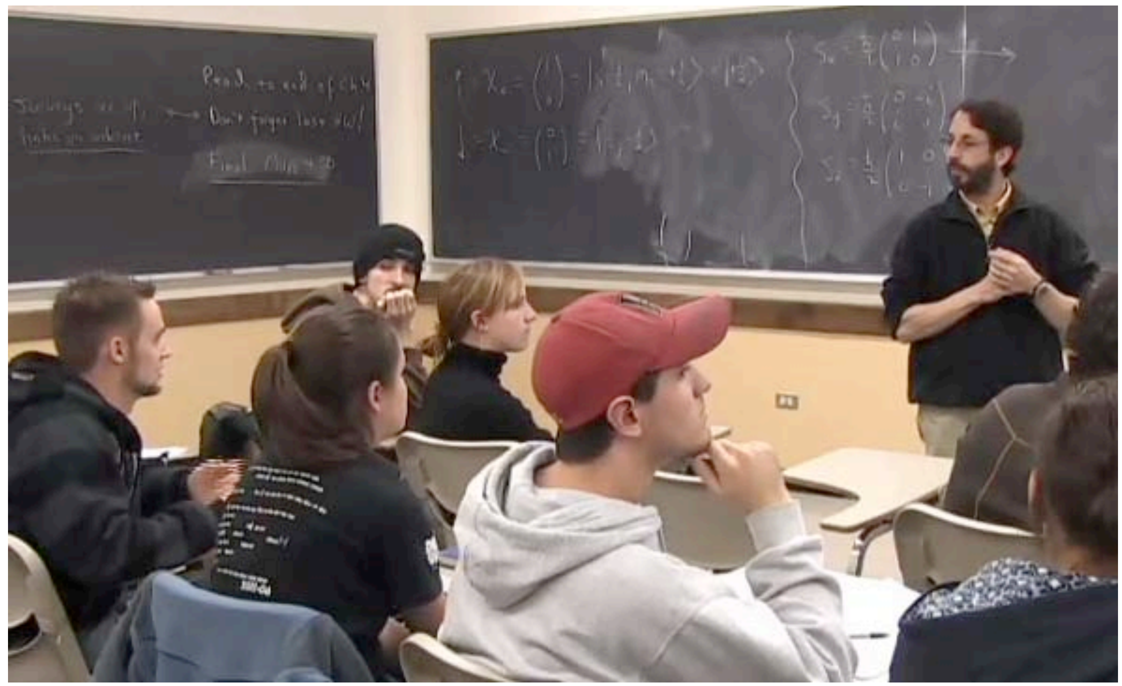
- Faculty collaboration
- Explicit learning goals
- Interactive classroom techniques
- Concept Tests
- Modified Homework
- Homework Help Sessions
- Tutorials

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

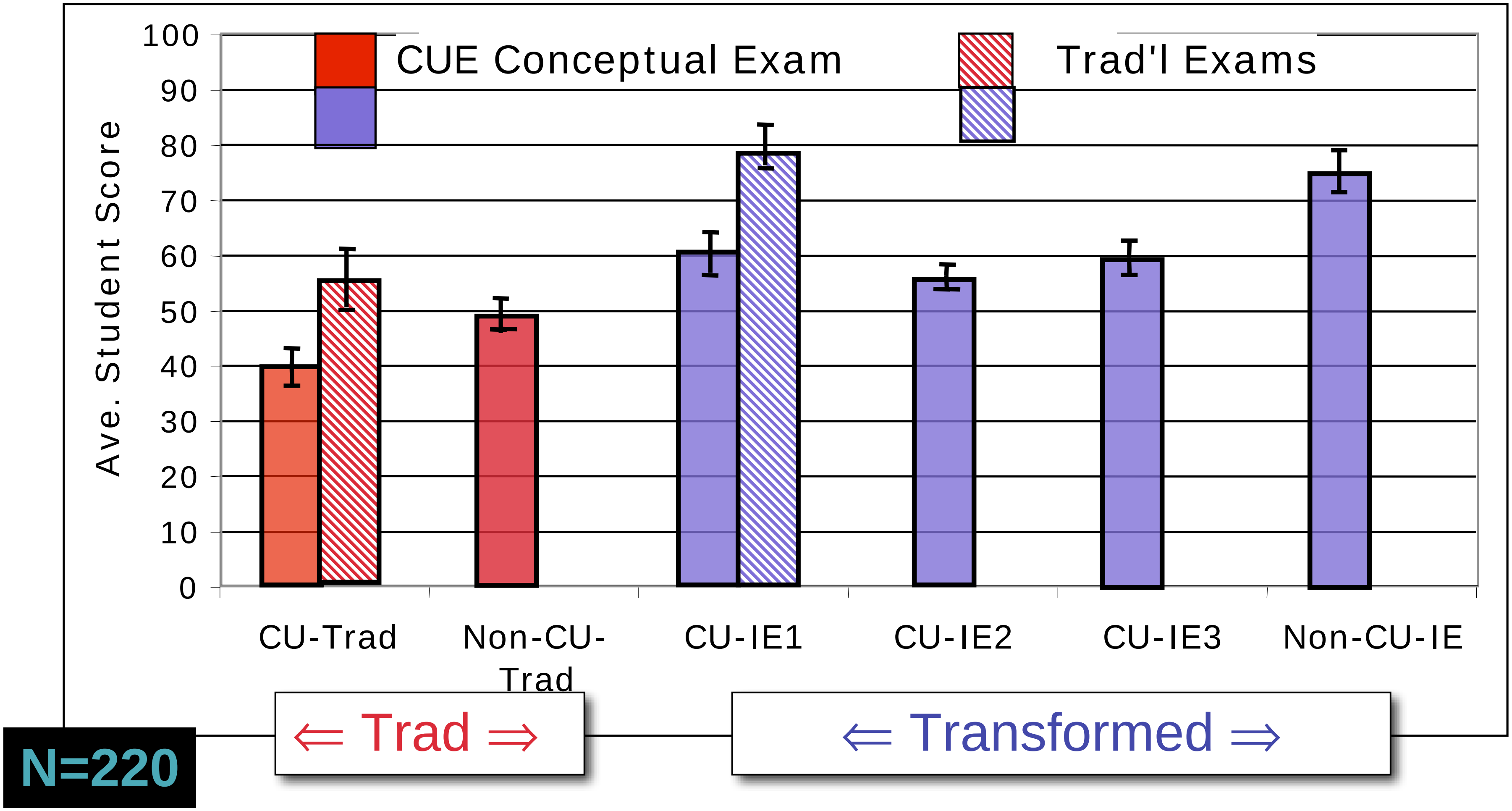
... be able to choose and apply the appropriate problem-solving technique

... 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

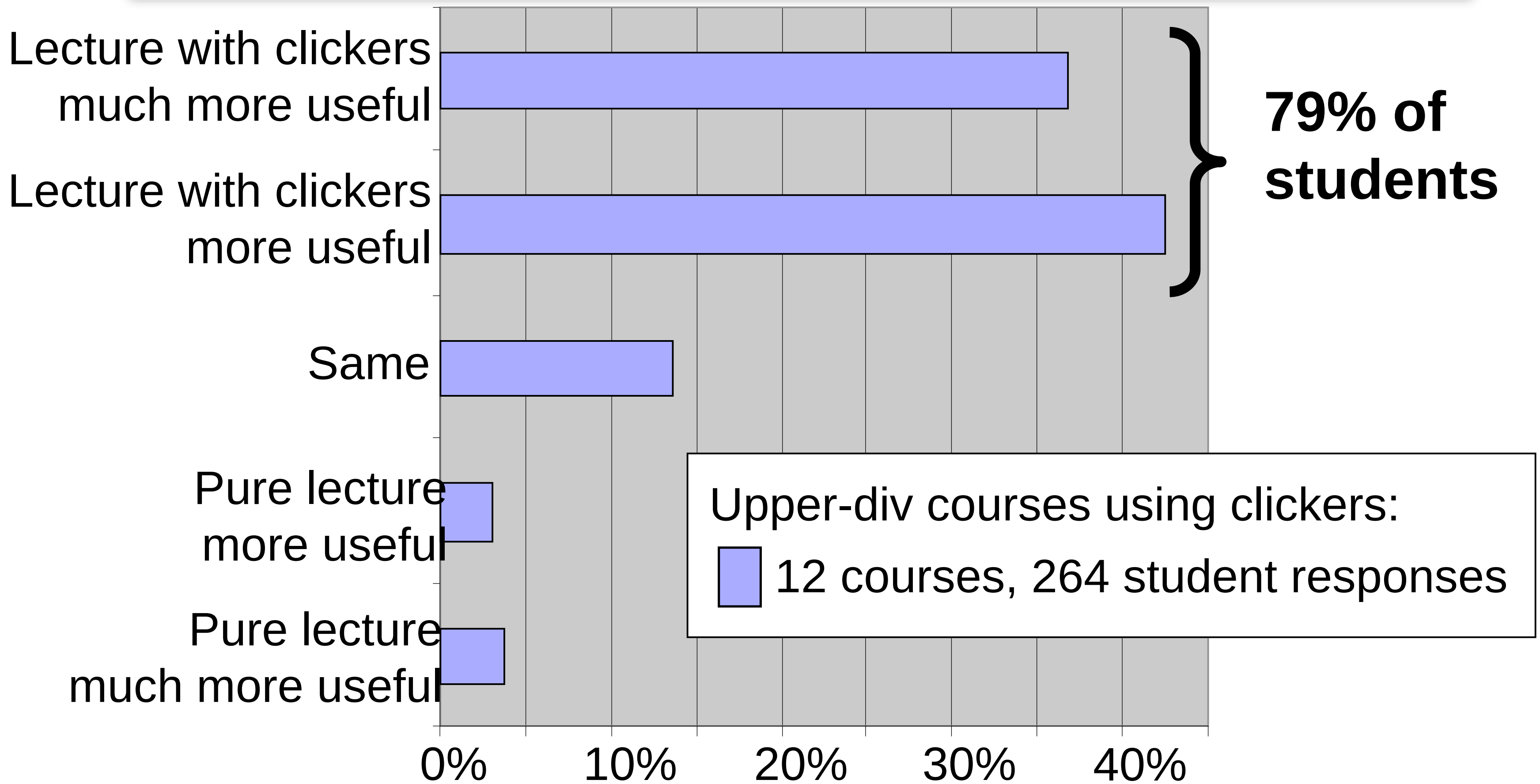
Results: CUE and Trad'l Exams



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

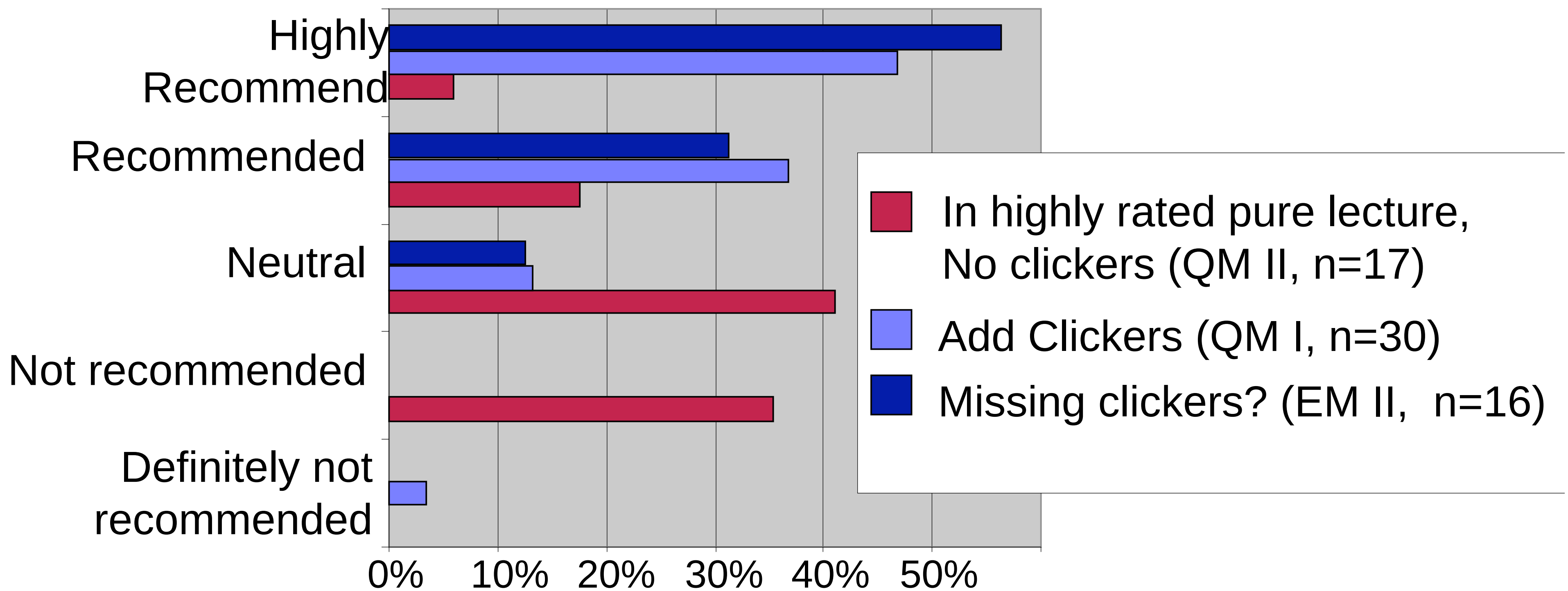
Students Find Clickers Useful

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



Student's can't predict value

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



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

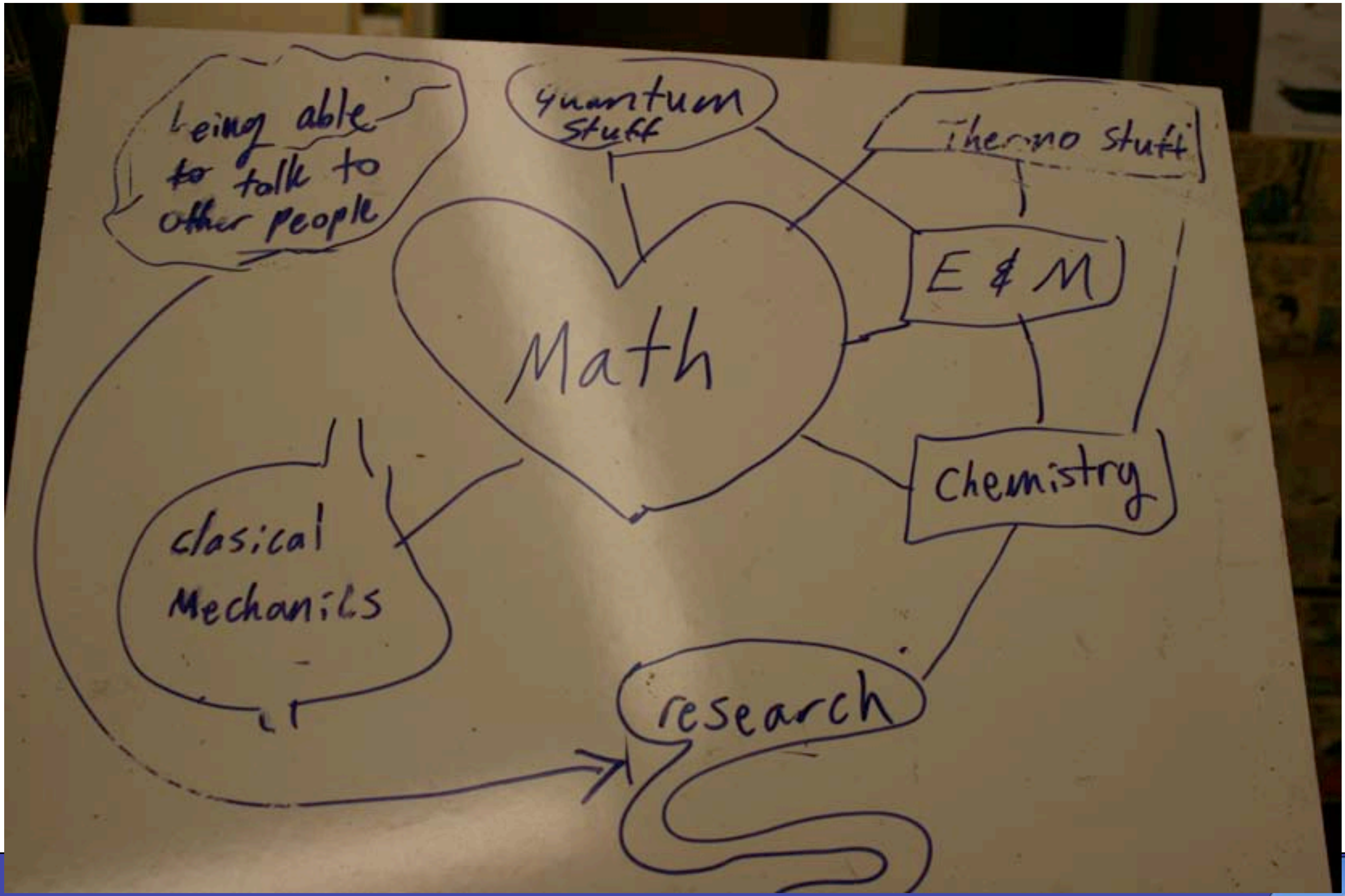
N=11 courses, 224 responses

Whiteboard activities

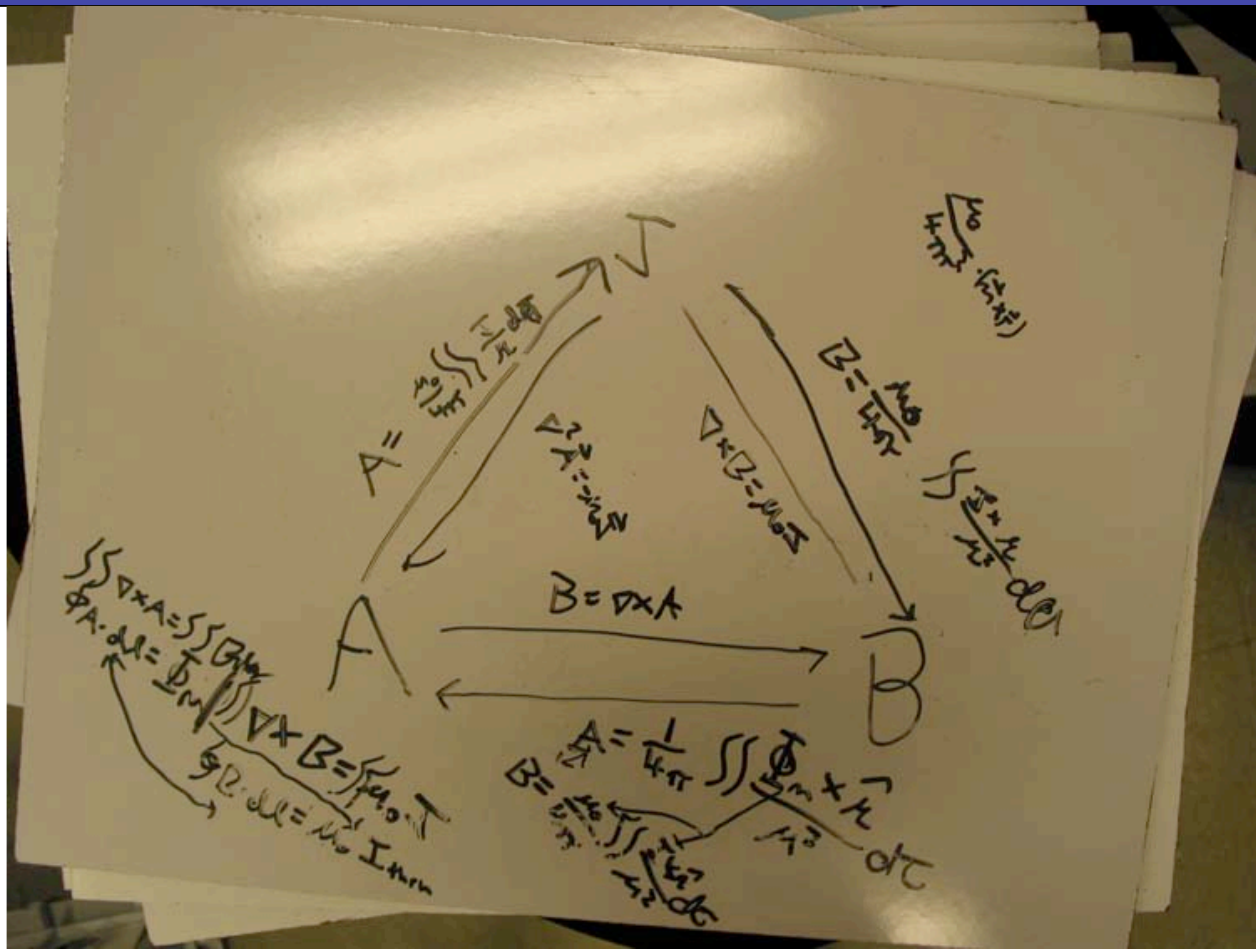
- 1X week
- Uncertain impact

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

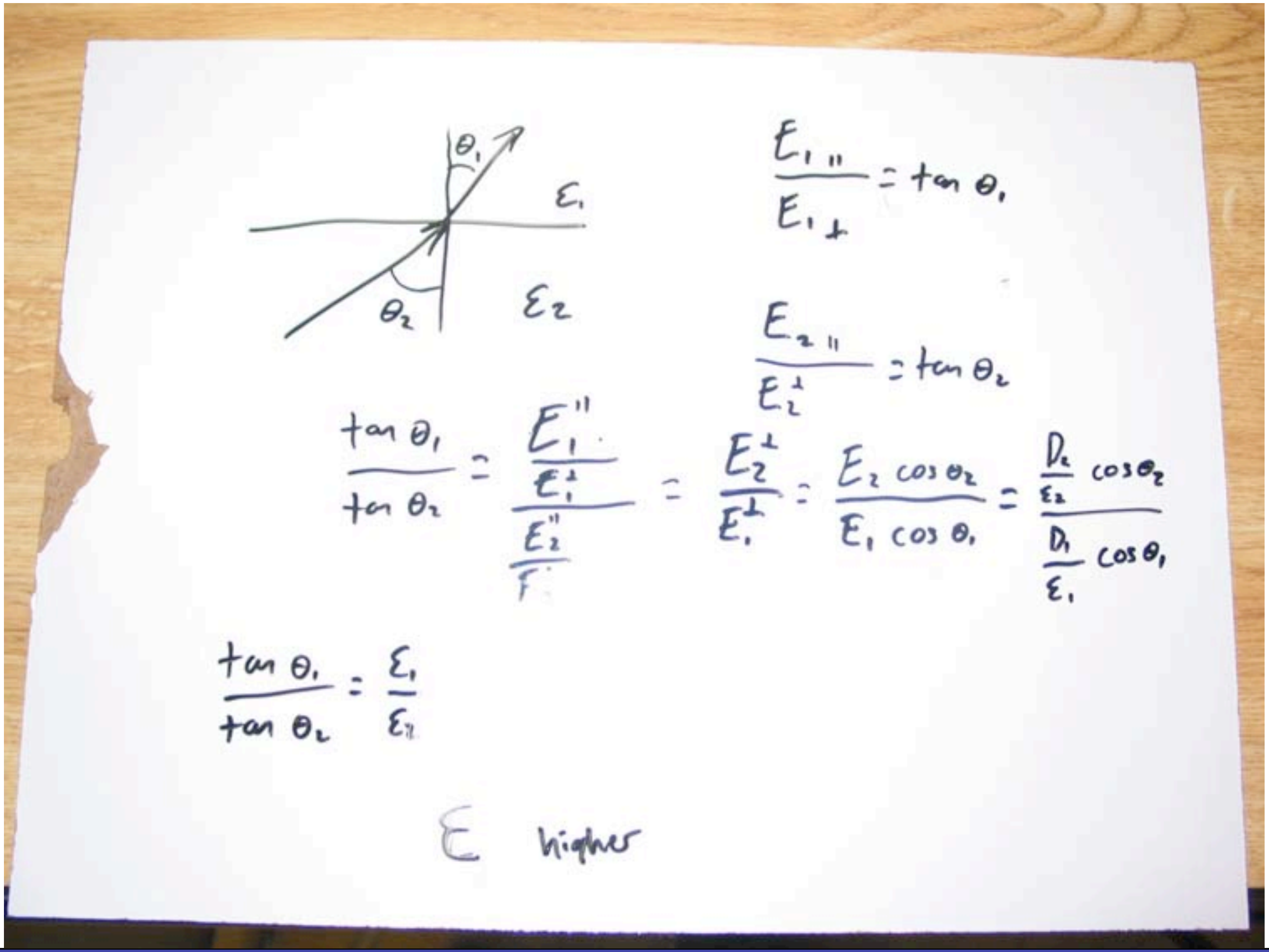
Concept map (whiteboard)



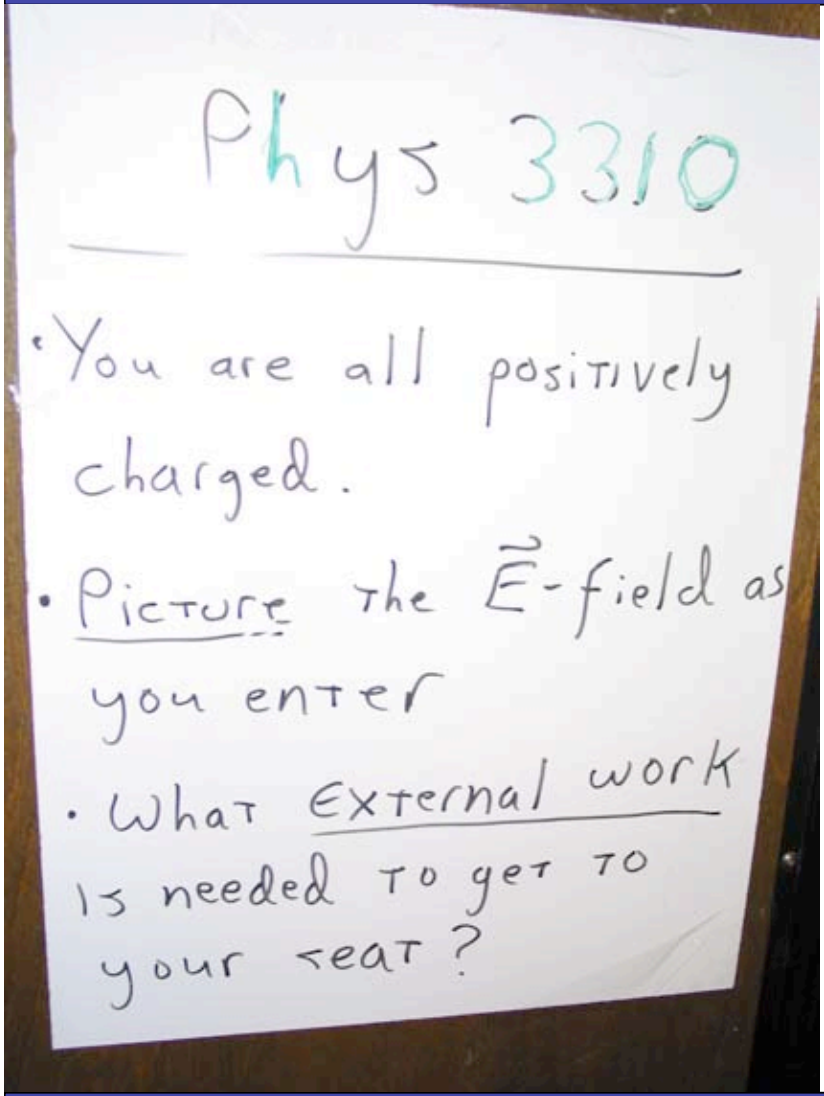
J-B-A triangle (whiteboard)



Boundary conditions for D/E



Kinesthetic activity



Largely built on OSU (Paradigms) materials

Concept Tests

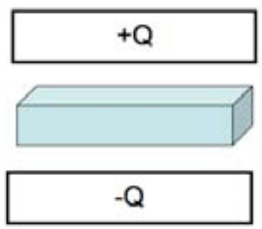
- Allowed students to **discuss & debate challenging, high-level ideas**

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

Where is D discontinuous?

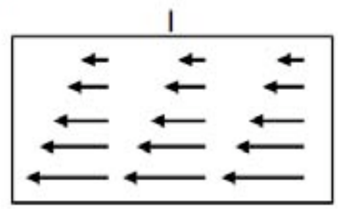
i) near the free charges on the plates

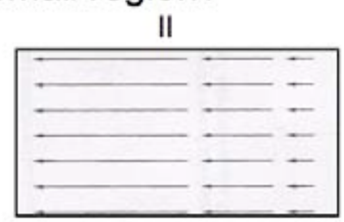
ii) near the bound charges on the dielectric surface



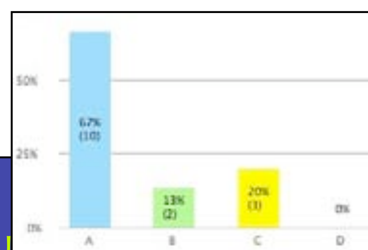
A) i only B) ii only C) i and ii ONLY
D) i and ii but also other places E) none of these/other

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



Homework

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

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?!)

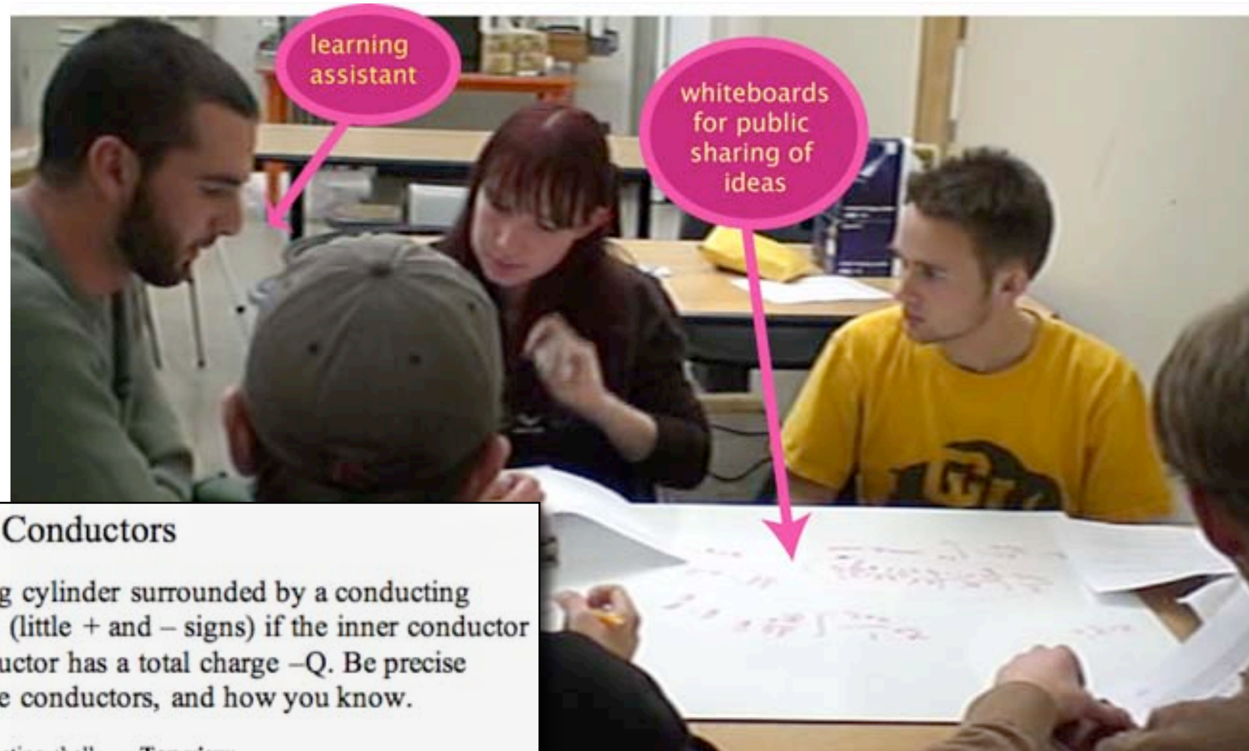
a) **Sketch it.** Calculate the divergence *and* the curl of this **E** field. Test your answers by using the divergence theorem and Stoke's theorem. **Is there a delta function at the origin like there was for a point charge field, or not?**

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 problem aligned with learning goals. Non-traditional portions in bold.

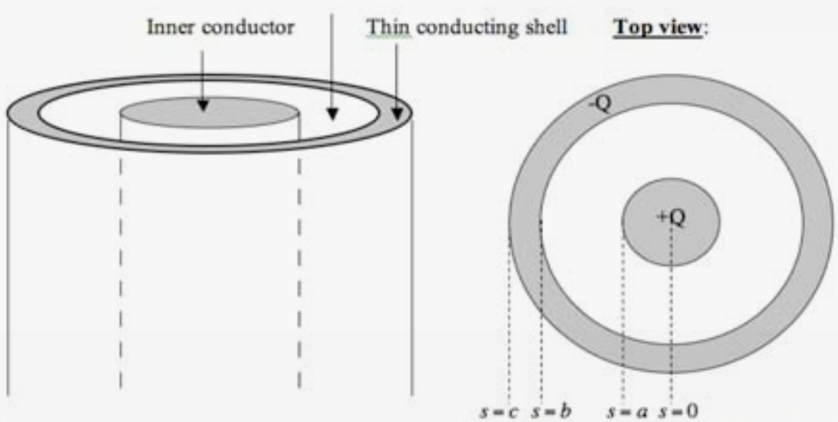
Tutorials & HW Help Sessions

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.

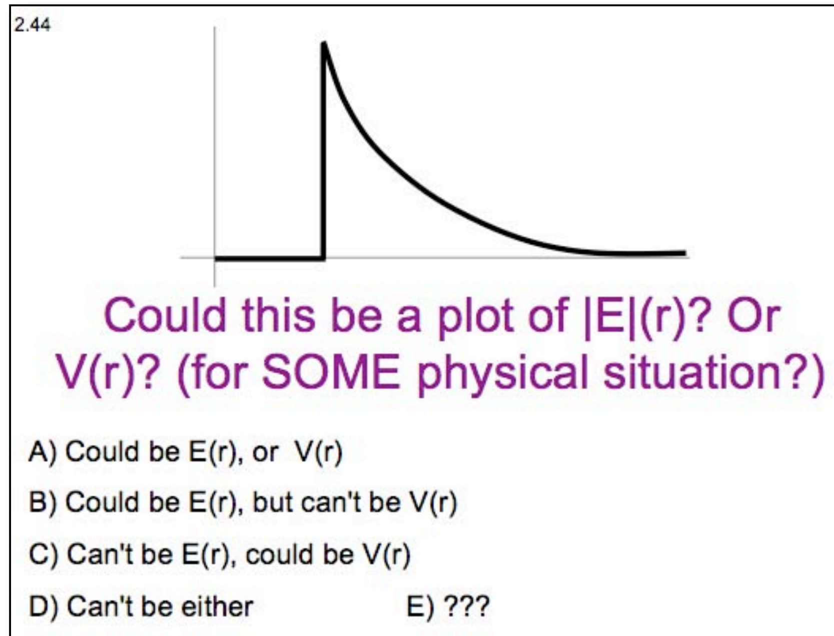


Portion of a CU tutorial

Example Questions

SP

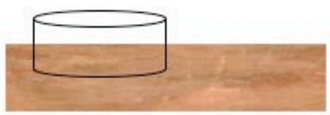
- Conceptual
- Math/Physics connection
- Application of ideas
- Step in calculation, proof, derivation



Questions: Fundamentals

2.34

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



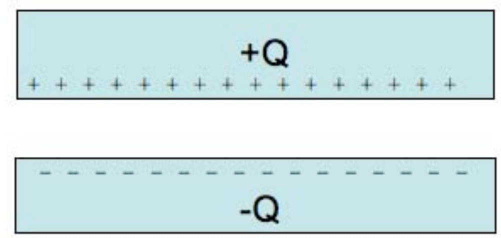
A) $|E| = \sigma/\varepsilon_0$
B) $|E| = \sigma/2\varepsilon_0$
C) $|E| = \sigma/4\varepsilon_0$
D) $|E| = (1/4\pi\varepsilon_0)(\sigma/s^2)$
E) $|E| = 0$

Freshmen: 45%, 60% next day

UD: 60 % correct

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

2.49 Given a pair of very large, flat, conducting capacitor plates with surface charge densities +/- σ, what is the E field in the region between the plates?

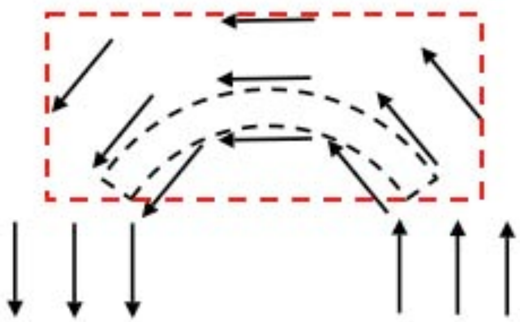


A) $\sigma/2\varepsilon_0$
B) σ/ε_0
C) $2\sigma/\varepsilon_0$
D) $4\sigma/\varepsilon_0$
E) Something else

Questions: Conceptual

5.17 b

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



$\vec{B} = B_0\hat{\varphi}$

A. Yes

B. No

C. Need more information to decide

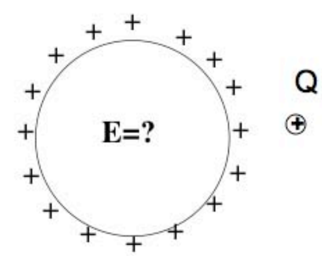
74% correct
("Need more info")

←

2.29 alt

A point charge Q is placed outside a uniformly charged shell of charge (uniform σ)

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

In general, given Hermitian operators A and B, and a state ψ, (and with the usual notation $\langle A\rangle=\langle\psi|A|\psi\rangle$ what can you say about

$$\langle\psi|\ \langle A\rangle\ B\ |\psi\rangle = ?$$

A) $\langle AB\rangle$

B) $\langle BA\rangle$

C) $\langle B\rangle\langle A\rangle$

D) MORE than one of these is correct!

E) NONE of these is, in general, correct!

Part of generalized uncertainty principle proof in QM

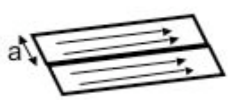
Questions: "Application"

- **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?

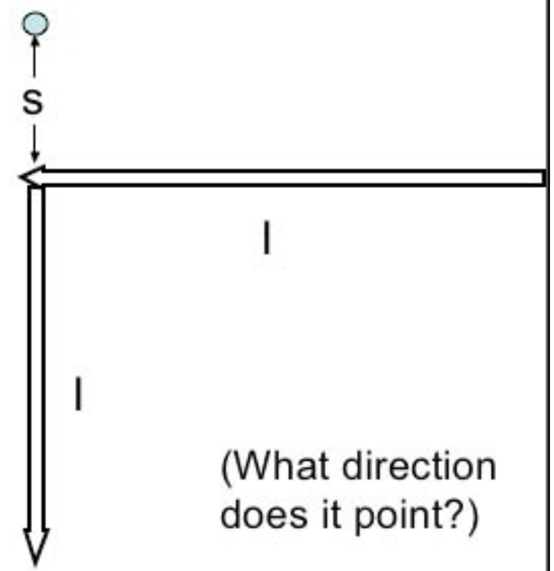
A) $\frac{\mu_0}{\pi\, s} I$

B) $\frac{\mu_0}{2\pi\, s} I$

C) $\frac{\mu_0}{4\pi\, s} I$

D) $\frac{\mu_0}{8\pi\, s} I$

E) None of these



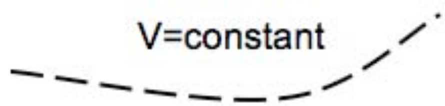
(What direction does it point?)

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

Research-based

- Tutorials
- Clicker Questions
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reflective development

Research-validated

- Consensus learning goals
- CUE instrument
- interviews and class observations

and next:

- pre/post Tutorial assessments

pre-tests

Week 4 puzzler

Page **1** of 1

Survey timer

Time remaining:

0:09:47

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*

pre-test (post lecture)

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%

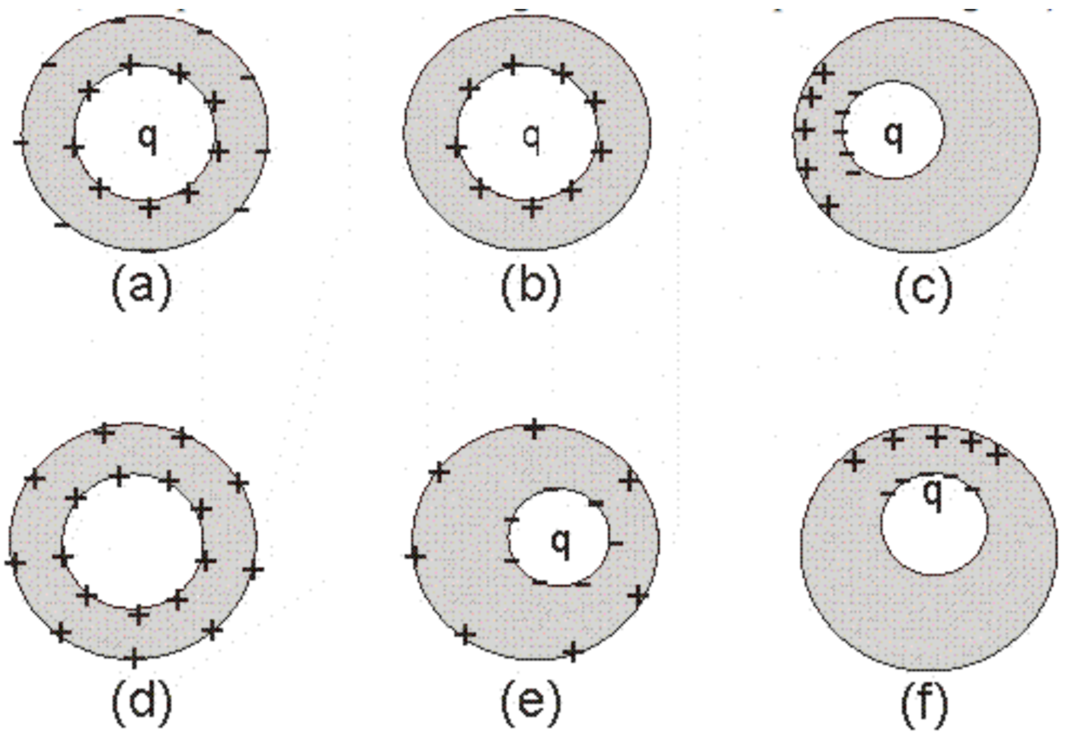
Can your third accomplice, who is outside the safe, figure out where to drill by measuring the electric field outside the safe? Please explain your reasoning

50%

pre-test (post lecture)

Which of the following could be a physically allowable static charge distribution?

Why/why not?



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:

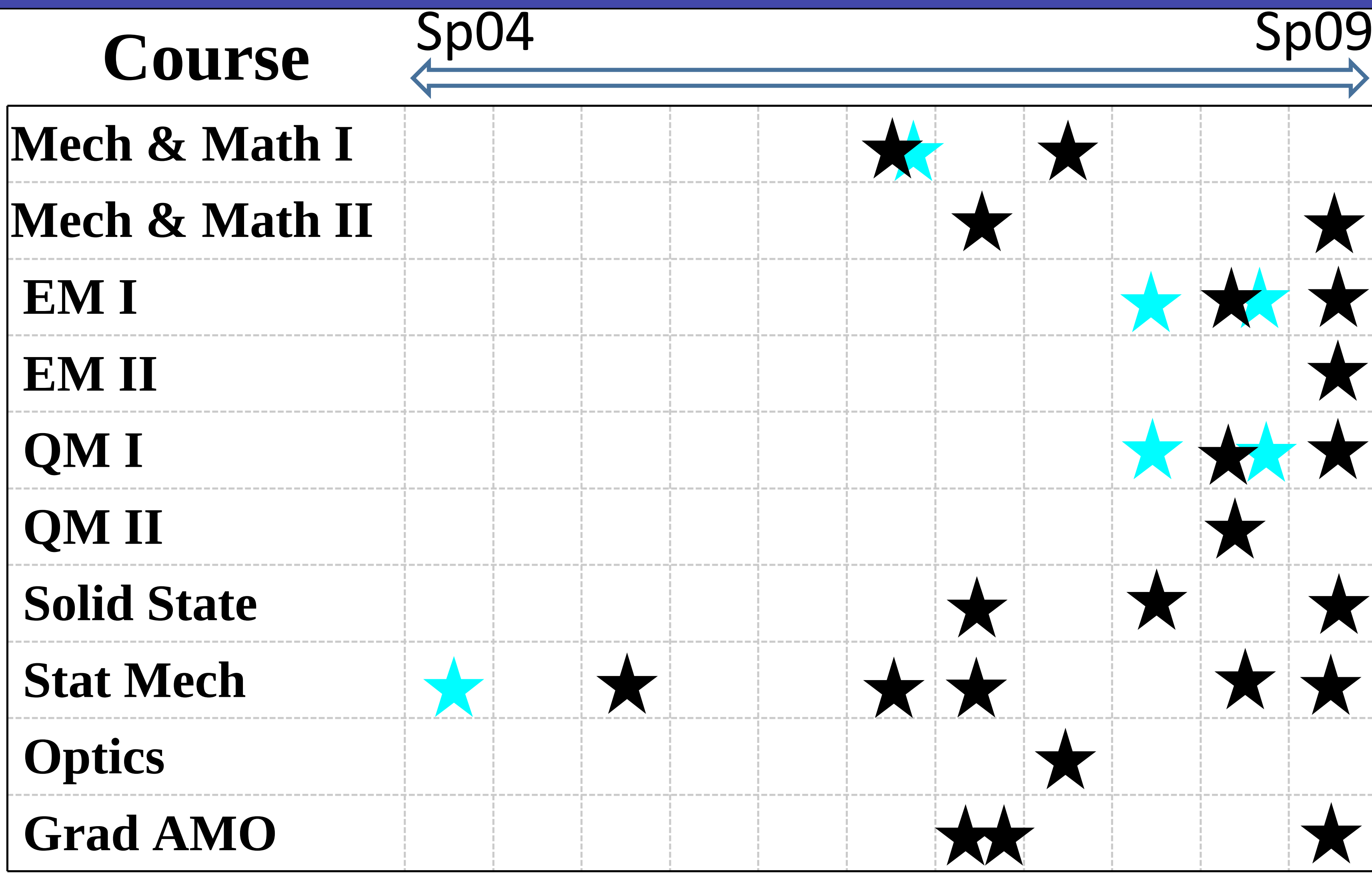
- Impact on content learning
- Impact on participation

Included faculty (buy-in?)

Developing materials and resources

Developing assessment instruments

Upper-div Clickers at CU



- 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