Interactive Engagement in the Upper-Level Courses

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Lessons from Paradigms project of Oregon State University
University of Colorado Boulder
• Work from **Oregon State University Paradigms** Project (*Liz Gire* and *Corinne Manogue*)

• And from **University of Colorado Boulder** (Stephanie Chasteen, Steve Pollock, and others in the physics education research group)

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Paradigms in Physics
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Raising Physics to the Surface
DUE-1612480
How is teaching upper-division courses different from teaching lower-division/intro courses?

Talk at your table as a whole group. Table with the LONGEST list gets a prize.
Active Learning In Upper Division

Opportunities & Challenges

Students:

• Strong personal interest
• Emerging identity as a physicist
• Planning to pursue physics-related careers
• More physics and math background

Content & Structure:

• Smaller classes
• No recitation
• Material is more advanced
Is doing active engagement in the upper division less “rigorous” for these potential future physicists? No: The principles of teaching and learning still hold!
Class Mech, Quantum, E&M, Adv. Lab, Modern [https://www.colorado.edu/sei/departments/physics](https://www.colorado.edu/sei/departments/physics)
The array of techniques
Classroom Techniques @ CU
Traditional lecture blended with interactivity.

- Explicit learning goals
- Modified HW
- Simulations & demos
- Small handheld whiteboards
- Clicker questions ("Think Pair Share")
- Kinesthetic activities
- Group activities / tutorials

OSU is more of a "flipped" class structure
Do we lecture? Yes!

There is a time for telling. It is just not too soon.

- Adapted from Dan Schwartz.
Lecture & Activities Complement Each Other

In Lecture...

The Instructor:
• Inspires.
• Covers lots fast.
• Models speaking.
• Models problem-solving.
• Controls questions.
• Makes connections.

In activities...

The Students:
• Experience delight.
• Slow, but in depth.
• Practice speaking.
• Practice problem-solving.
• Control questions.
• Make connections.
Learning goals and assessments
What are learning goals?

- What students should do as a result of instruction.
- Align **goals**, **assessment**, and **instruction**
- Called “**Backwards Design**” approach

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**Learning goals**

Students should be able to… interpret graphs and use them to predict behavior.

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**Assessment**

Exam: Show students graphs of potential energy: Which of these points on the graph is stable? Why?

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**Instruction & feedback**

Group activity with topographic maps as an analogy for potential energy.

HW applications.
Learning Goals

- From faculty group
- Framed course transformations & assessment
- 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

Discuss (3 min) How might you know if a student had achieved any one of these goals?
An example assessment question

**Goal:** Students should … be able to choose and apply the appropriate problem-solving technique

*DO NOT SOLVE* the problem, we just want to know:
- The general strategy (half credit)
- Why you chose that method (half credit)

A solid non-conducting sphere, centered on the origin, with a non-uniform charge density that drops off as 1/r. Find E (or V) at point P.

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*Colorado Upper-Division Electrostatics Assessment, open-ended version*
Griffiths:

Consider a field \( \mathbf{E} = c \frac{\mathbf{r}}{r^2} \).

Calculate the divergence and the curl. Test your answers using the divergence and Stoke's Theorems.
Griffiths’ calculation HW doesn’t address our learning goals

Griffiths:
Consider a field $\mathbf{E} = c \frac{\mathbf{r}}{r^2}$.

Calculate the divergence and the curl. Test your answers using the divergence and Stoke's Theorems.

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
Consider a field \( \mathbf{E} = c \frac{\vec{r}}{r^2} \).

A) Sketch it.

B) Calculate the divergence and the curl. Test your answers using the divergence and Stoke's Theorems.

C) What are the units of \( c \)?

D) What charge distribution would you need to produce this \( \mathbf{E} \) field? Is this a \( \delta \)-function at the origin? Is it physically realizable?
Kinesthetic Activities
Kinesthetic Activities

- Stand up.
- Each of you represents a point charge.
- Make a linear charge density.

Students form a non-uniform line charge
Complex Numbers with Arms

\[ z = e^{i\phi} \]
\[ z = |z|e^{i\phi} \]
\[ z = a + bi \]

Hahn, Gire, & Manogue, AJP, accepted
Spin states

Arms Representation of Quantum States

Represent the state:

$$|\psi\rangle = \frac{1}{3} |1\rangle + \frac{\sqrt{8}}{3} e^{i\pi/4} |1\rangle$$

See Hahn, Gire, and Manogue
American Journal of Physics
Clicker questions ("Think Pair Share" / Peer Instruction)
Clickers
Electronic response systems with histogram and anonymous vote. Different way to do Ed’s Think Pair Share. Also polleverywhere.com
The anatomy of a clicker question

Ask Question

Ask Question

...Lecture...

Class Discussion

silent vote

Peer Discussion

Re-Vote

PER © CU-Boulder
Which of the following could be a static E field in a small region?

I

II

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

\[ \nabla \cdot E = \frac{\rho}{\varepsilon_0} \]

\[ \nabla \times E = 0 \]
Example Questions

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

Look through your lecture notes for question opportunities

Correct answer D: Step in a calculation

To find the E-field at P from a thin line (uniform linear charge density λ):

$$E = \frac{1}{4\pi\varepsilon_0} \int \frac{\lambda}{\sqrt{\mathbf{r}^2}} \lambda \, dl'$$

What is $$\mathbf{R} = |\mathbf{R}|$$?

A) X  B) y'  C) $$\sqrt{dl'^2 + x'^2}$$  D) $$\frac{x^2 + y'^2}{\sqrt{x^2 + y'^2}}$$  E) Something completely different!!

For more see TPS breakout session later
Clicker questions in upper division

https://www.youtube.com/watch?v=xxigdSbL3CM

More videos on clickers and interactive engagement across the curriculum at STEMclickers.Colorado.edu
Questions so far on upper division reforms, learning goals, clickers?

Next up: group activities, whiteboards
Group activities: Worksheets and small whiteboards
On your whiteboard, write down something you know about the dot product.
Recall is harder than Recognize

Have students practice recall before an exam.
Small Group Activities

- 2-3 students, each with pen
- Whiteboard or worksheet
- Hard problems
- Instructor facilitates
- Students share reasoning with the whole class
- Wrap-up discussion is crucial

In breakouts you can hear about upper division tutorials
Brainstorm:
Neighbor chat: What are the benefits/challenges of Worksheets vs Whiteboards

Part 1 - Conceptual
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.

Inner conductor  Thin conducting shell  Top view:

\[ E_x = \frac{E_{1x}}{\sin \theta}, \quad E_{x_2} = \frac{E_{2x}}{\sin \theta}, \quad E_{x_3} = \frac{E_{3x}}{\sin \theta}, \quad E_{x_4} = \frac{E_{4x}}{\sin \theta} \]

\[ E_x = E_{1x} \cos \theta, \quad E_{x_2} = E_{2x} \cos \theta, \quad E_{x_3} = E_{3x} \cos \theta, \quad E_{x_4} = E_{4x} \cos \theta \]

\[ E_{x_1} = E_{1x} \sin \theta, \quad E_{x_2} = E_{2x} \sin \theta, \quad E_{x_3} = E_{3x} \sin \theta, \quad E_{x_4} = E_{4x} \sin \theta \]

Whiteboard
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.

Inner conductor

Thin conducting shell

Top view:

\[ s = c \quad s = b \quad s = a \quad s = 0 \]
OSU: Whiteboard pedagogy: Peer instruction in flipped structure
Whiteboard pedagogy

Viewable artifact. Can be made “anonymous” during share-out
Example white board question

Calculate: \[ \vec{a} \cdot \vec{b} \]

where \[ \vec{a} = 4 \hat{my} \]

\[ \vec{b} = 2 \hat{m}, 60^\circ \text{cw from } +x \]
Turn HW question into a whiteboard question

Griffiths problem 5.15

Two long coaxial solenoids each carry current I but in opposite directions.
The inner solenoid (radius a) has n₁ turns per unit length, and the outer one (radius b) has n₂.

Find B (i) inside the solenoid, (ii) between them, and (iii) outside both.
An infinite line is uniformly charged with a linear charge density \( \lambda \). Find a formula describing the electric field at a distance \( z \) from the line.

**You write**

What formula do we use?

Can you draw the Gaussian surface?

\[
\oint_{la} \vec{E} \cdot n \, dS = \oint_{la} E n \, dS = \oint_{la} E dS.
\]

**They write**

\[
\oint_S \vec{E} \cdot d\vec{S} = \frac{Q}{\varepsilon_0}
\]

Evaluate this integral

\[
\oint_{la} \vec{E} \cdot n \, dS = E 2\pi z l
\]
Concept mapping can be a good way to organize knowledge to see the big picture.
Small Whiteboard Questions

Great for

› Review
› sketching
› multiple representations,
› short calculations
› “next step”

Keep it short!
In groups of 2-3: Invent your own small whiteboard question (10 minutes)

- Suggestion: Build on the clicker question below.
- Alternatively, take something from a recent course you taught.
- Can you build to the next step? Help students recall? Apply?
- Write it on your whiteboard

Which of the following could be a static E field in a small region? (Answer: B)

A

B

\[ \nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \]

\[ \nabla \times \vec{E} = 0 \]
Talk with your group, and be ready to share out

• In what context would you ask this question?
• What are you hoping to learn about your students by asking this question?
• What student responses are you anticipating? (Difficulties & various forms of a correct answer?)
• What discussions could you have with your class around these responses?
Questions or comments on whiteboard activities?
Closing thoughts
Establish classroom norms that everyone sometimes gets things wrong

• It is the truth
• Promotes equity
• Encourages collaboration (it take courage to be publicly wrong)
• Isn’t how we are used to doing things!
Conceptual understanding doesn’t come along for free
Talk to other instructors
Summary

- Active learning pedagogies can work very well in advanced physics courses.
- Well-timed lectures enhance active learning
- Peer instruction, whiteboards, worksheets, kinesthetic activities, tutorials; many are developed
- Wrap-up discussions are essential
- Start small
- Listen to students
Want to learn more?
Paradigms in Physics

paradigms.oregonstate.edu

Welcome to the Paradigms in Physics curricular materials website!

This site is under construction, and currently the easiest way to find curricular material that you're interested in is with the search bar on the upper right. If you're interested in browsing our content, probably the most useful approach is to browse the sequences of activities and homework.

Activities

Sequences

Homework Problems

Teaching Tips

Courses

Learning Progressions

Visit our OSU PER group website for more information about related research.

Featured Searches:

quantum angular momentum spin arms kinesthetic "Raising Physics to the Surface"
CU Boulder Material

Upper division CU SEI collection page
https://www.colorado.edu/sei/departments/physics/activities/courses

Videos on clickers and more
http://STEMclickers.Colorado.edu

Physport hosts CU’s quantum materials at
https://www.physport.org/curricula/ACEQM/

New beta-version quantum tutorial resource is at
https://acephysics.net/