Upper-Division Transformations in Physics

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Overview

Adapting research-based teaching approaches to upper-division courses.

Junior-level Electricity & Magnetism (E&M) and Quantum Mechanics

Why Upper Division?

Sophisticated problem-solving courses usually taught with traditional lecture and abstract formalism.

Highly valued by faculty.

These courses define what it means to learn physics as a major. Can we do better?

Departmental History

Using clickers with peer instruction and interactive tutorials at the freshman level.

Using clickers in 10 upper-division & graduate courses.

Some departmental culture of using interactivity in teaching.

Learning Goals

Ten broad learning goals were developed by a working group of 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.

Topic-specific goals were developed for each course. Learning goals drove course instruction & assessment.

Classroom Techniques

- Interactive lecture
- Kinesthetic activities (E&M only)
- Small whiteboards
- Clicker questions and peer discussion

2-3 challenging questions per lecture: Examples below.

Homework

Modified traditional homework to match learning goals.

For example, we added:
- Real-world contexts
- Making sense of answer
- Approximations, expansions, estimations...

Modified traditional homework.

Assessments

E&M: The CUE (Colorado Upper-Div. Electrostatics)

- 17-question open-ended conceptual diagnostic; correlates with grades
- Developed from student interviews and faculty

Quantum: The QMAT (Quantum Mech. Assessment Tool)

- 14-question mostly open-ended conceptual diagnostic
- Developed from student interviews, faculty learning goals and prior research
- Probes student learning in time evolution, wave functions, the Schrödinger eq., measurement, and probability
- Results indicate significant student learning difficulties in areas of measurement and time development.

Students in E&M courses using the transformed materials scored higher on the CUE & traditional exams.

References & Acknowledgements

We acknowledge the generous contributions of the faculty working group at CU, as well as the contributions of two undergraduate Learning Assistants, Ward Hadley and Tabitha Tisdale, and the student research assistants of CU. We are grateful to the instructors at four outside institutions who administered the CUE in their courses.

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Results & Conclusions

- We have transformed junior-level Quantum and E&M to be more closely aligned with principles of how people learn
- Compared to a traditional lecture, students scored higher on traditional and conceptual assessments in E&M (Quantum assessments ongoing).
- Students’ reactions were positive about course changes.

Pedagogical techniques that improve learning in introductory classes can have similar benefits in upper-division, enhancing the education of future physicists, teachers and engineers.

Tutorials

- Added optional weekly co-seminar (~50% attendance)
- Socratic guided inquiry
- Run with assistance of undergrad Learning Assistant
- In addition to twice weekly HW help sessions

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

Homework

Sample HW: Non-traditional portions in bold.

QQ. DIVERGENCE AND CURL

Consider a field F = \( \mathbf{F} \) (which is NOT the field from a point charge at the origin, right?)

a) Sketch it. Calculate the divergence and curl of this E field. Test your answers by using the right-hand rule (and left-hand for toroidal, in a toroidal field like this). Describe it in words as well as formulas. (Is it physically realizable?)

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