Ten broad learning goals were developed by faculty. Content is canonical: Griffiths used in order to evaluate effectiveness of the transformations and align with faculty values. A working group of ~10 PER and non-PER faculty met biweekly to discuss course learning goals and content. All course materials are available online at www.colorado.edu/sei/departments/physics_3310.htm.

Learning Goals

Content is canonical: Griffiths' Chapter 1-6. Ten broad learning goals were developed by faculty. For example:

- Students should be able to achieve physical insight through the mathematics of a problem.
- Students should be able to choose and apply the appropriate problem-solving technique.
- Students should be able to justify the reasonableness of a solution (using limiting cases, units, etc.)

Class blended traditional lecture with interactive engagement methods -- not as dramatic a departure from the traditional approach as other transformation efforts. Techniques included:

- Interactive lecture style involving high levels of student-student and student-teacher interaction.
- Clicker questions and peer discussion.
- Illustrative simulations and demonstrations.
- Kinesthetic activities such as pointing to indicate unit vectors, or forming a line charge.

Student work on small whiteboards. E.g., sketch a function, solve problem, make concept map.

Why Upper-Division E&M?

- Electricity & Magnetism:
  - Is a core course for majors
  - Defines what it means to learn physics as a major
  - Requires sophisticated problem-solving
  - Is often taught using traditional lecture
  - Is often taught through abstract formalism
  - Has canonical content

E&M is highly valued by faculty as a core course for training majors; so changes can be departmentally sensitive.

Our efforts got at the heart of what the department wishes its majors to learn.

Classroom Techniques

- Concept Tests (clickers)
  - 2-3 clicker questions in each 50-min class
  - 5-7 minutes per clicker question
  - Allowed us to gauge student understanding
  - Allowed students to discuss challenging ideas
  - Kept students engaged and following lecture
  - Asked student to expand or apply lecture topics
  - Prepared students to learn from lecture

- Homework Help Sessions
  - Two 2-hour sessions per week
  - Optional (65% class attendance)
  - Instructor assisted in Socratic style
  - Helped students solve homework problems

- Tutorials
  - 10 weekly tutorials* under continued development
  - Optional (50% class attendance)
  - Socratic guided inquiry
  - Run with assistance of undergrad Learning Assst.
  - Prepared students for next homework by helping them conceptually interpret the mathematics

- Homework

In order to more explicitly target learning goals, we modified traditional homework. For example:

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

Results & Conclusions

Success of the transformation was evaluated by:

- New conceptual assessment (CUE) and BEMA.
- Conventional exam problems.
- Student interviews and end-of-term evaluations.
- Compared to a traditional lecture, students scored higher on all assessments (see other poster), and were very enthusiastic about the course.

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.

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

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

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References

[9] BEMA scores were not statistically significantly different.

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