Overview

We are adapting research-based pedagogical techniques in an upper-division course [1] (clickers, tutorials, modified HW, etc.).

The CUE instrument [2] has been developed to measure student’s progress towards learning goals, and as a tool to investigate student thinking at this level.

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

Learning Goals

Our course content is canonical[3]. 10 broader learning goals were developed by PER and non-PER faculty, including e.g.:

- MATH/PHYSICS CONNECTION: achieve physical insight through use of math
- VISUALIZATION: sketch physical parameters
- COMMUNICATION: justify and explain their thinking & approach.
- PROBLEM-SOLVING: choose & apply appropriate techniques

These goals represent often implicit expectations of faculty, and drove transformed instruction[2,4] & assessments.

Colorado Upper-Division Electrodynamics (CUE) Assessment

- CUE is a 17-question conceptual assessment.
- Inter-rater reliability on CUE was within 10% for all students, 5% for most (76%), Chronbach cr=.82, ave. diff of 1.4% ± 0.6%
- Given to 226 students.
- 4 of 9 courses to date used transformed materials.
- CUE scores are low: This is a challenging test.

Student Performance on Learning Goals

<table>
<thead>
<tr>
<th>Learning Goal</th>
<th>Description</th>
<th># of Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Math/Physics</td>
<td>Physical meaning of equations</td>
<td>3</td>
</tr>
<tr>
<td>2. Visualization</td>
<td>Sketching, graphing</td>
<td>3</td>
</tr>
<tr>
<td>3. Communication</td>
<td>Explanations &amp; justifications</td>
<td>9-11</td>
</tr>
<tr>
<td>4. Problem-Solving</td>
<td>(a) Correct method for problem</td>
<td>(a) 6-7</td>
</tr>
<tr>
<td></td>
<td>(b) Specific skills</td>
<td>(b) 12-14</td>
</tr>
</tbody>
</table>

(Varying # of questions per category due to ongoing CUE development)

Example: Visualization

E.g. Q10: Sketching E field around a conductor in an external field (average score 62%).

- Problem requires students to use superposition [but many draw non-zero E inside (40%), or just E₀ outside (19%)] fields as lines of force [most draw correct charge distribution, but many draw non-zero E inside, or nonphysical fields]

Such responses allow faculty to reflect on students’ cognitive resources and difficulties. Sketches contain useful elements (remembered or derived) about polarization, shielding and superposition, and boundary conditions, but frequently miss the desired synthesis of physical intuitions faculty seek to teach.

Communication: Reasoning & Justification

- Poor performance on this learning goal, particularly in traditionally taught courses
- This skill is not supported in trad. instruction or generally valued on assessments

Problem Solving: Choosing Methods

E.g. Q2 (a “cubical” dipole charge distribution) only 42% get full credit. 13% choose Gauss’ Law (despite lack of appropriate symmetry)

- Many students answer “direct integration”, (57% make some mention of dipole/multipole.)
- Many students give same answer for both; miss significance of field point
- Many students fall back on direct integration (in this and many situations).
- On the CUE and in interviews, students struggle both to identify and to connect the numerous solution methods.

Students demonstrate strong use of formal methods, but novice-like conceptual organization. Students show persistent difficulties in extracting essential features of problems, and are frequently unaware when a given method is not appropriate or practical, with over-reliance on mathematical formalism. (“Just do the integral!”)

Limits/Approximations

- Students perform particularly poorly on Q6 (B from current loop) 40% use direct integration, only 25% mention dipole/multipole.
- On Q12 (E of disk, z<<R) ave score only 43%
- Many claim that E goes to 0 at disk. Others observe E goes to 0 at ∞, but do not answer the question of functional dependence.

Superposition

E.g. Q5: (sphere with cavity), 44% get no partial credit, 25% answer “Gauss’.”

Students require additional support in developing physicists’ skills (which faculty may assume develop naturally in the course); moderate improvement when skills are directly targeted through IE

Conclusions

- The CUE has value in assessing our courses, and also in investigating student thinking.
- Transformed (interactive engagement) courses can make progress towards helping students achieve our faculty’s consensus learning goals, but there is a long way to go.

Further research is needed to help support and develop students’ abilities in:

  - Communicating and justifying their ideas
  - Interpreting math and connecting it with physics ideas.
  - Appropriately applying many lower-division concepts (e.g. superposition, or Gauss’ law)
  - Using many elements of the physicist’s toolbox, such as superposition, symmetries and approximations.

Many of these skills are generally assumed by faculty at this (upper-division) level.

References & Acknowledgements

[6] E.g., 22% answer “direct integration”, (57% make some mention of dipole/multipole.)

We acknowledge the generous contributions of the faculty working group at CU, and two undergradaute Learning Assistants, Ward Handlely and Darren Tarshis, and the PER group at CU. We are grateful to the instructors at 4 outside institutions who administered the CUE.

This work is funded by The CU Science Education Initiative and NSF-CCLI Grant #0737118.

All course materials and CUE are available online at www.colorado.edu/sei/departments/physics.htm