**Overview**

As part of a research-based effort to improve junior level E&M concepts, we created a conceptual assessment to evaluate student understanding of upper-division E&M concepts -- the Colorado Upper-Division Electrodynamics (CUE) Assessment. Preliminary validation and results are presented. All course materials & the CUE available: www.colorado.edu/sei/departments/physics_3310.htm

**Learning Goals**

Content in course is canonical: Griffiths’ Chapter 1-6. Ten broad learning goals were developed by a working group of 10 faculty, including:

<table>
<thead>
<tr>
<th>Goal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH/PHYSICS CONNECTION</td>
<td>... achieve physical insight through the mathematics of a problem</td>
</tr>
<tr>
<td>VISUALIZE</td>
<td>... sketch the physical parameters of a problem</td>
</tr>
<tr>
<td>COMMUNICATION</td>
<td>... justify and explain their thinking and approach to a problem</td>
</tr>
<tr>
<td>PROBLEM-SOLVING</td>
<td>... choose and apply the appropriate problem-solving technique</td>
</tr>
</tbody>
</table>

E&M defines what it means to learn physics as a major. These goals represent often-implicit expectations of faculty. Goals drove instruction in transformed courses¹ as well as the development of CUE.

**About the CUE**

- A 17-question conceptual assessment to be given in 50-minute lecture
- Optional 7-question (20-minute) pre-test
- Aims to measure achievement on learning goals
- Detailed grading rubric developed
- Mostly short answer with one multiple choice question
- Asked students to:
  - Choose a problem-solving method & defend that choice, sketch E field patterns, graph electric field strength and potentials, and explain the physics and mathematics underlying steps in common problems

**Validation & Reliability**

- Validated in think-aloud interviews & 3 semesters of test administration
- 7 questions dropped, 2 questions added, 5 questions substantially modified to arrive at final instrument
- CUE score moderately correlated with course grade (r=0.49, p<0.01) at CU
- Good reliability as measured by Cronbach’s alpha (0.82)
- Inter-rater reliability on total CUE score is high (as tested by 36 exams scored by two experienced graders)
  - Average difference of 1.4% ± 0.6% – much less than interclass differences given in Results, below.
  - Graders agree within 10% for all students and within 5% for most (76%) students
- Inter-rater reliability per question on CUE is acceptable:
  - Within “close” agreement for 75% of students on all questions but two
  - In exact agreement for at least 45% of students on all questions but one
- Standard deviation of rater-differences on questions range from 0 to 28% (average 12%)

On average, we can discern CUE scores within 5% overall and 20% per question.

**Results**

The post-test was given to 226 students at CU and elsewhere.
- Four courses were taught using the transformed course materials (IE1-3 at CU and C-IE at a private liberal arts college) using student-centered instruction such as clickers and tutorials, and homework based on learning goals.
- All courses using the transformed materials scored higher on the CUE than courses not using the materials.
- Three instructors using transformed curriculum (IE1, IE2, and C-IE) had never taught E&M before, yet received high CUE scores, suggesting curricular rather than instructor effects.

**Conclusions**

- We have developed an open-ended assessment that taps students’ mastery of some of the skills expected of a junior E&M student.
- We have invited poster session for detailed analysis of student responses.
- The assessment shows good validity and reliability such that interclass differences can be discerned; analysis still in progress.
- The CUE appears to measure differences that we care about -- such as the effect of pedagogical transformations and student population.

**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 Handley and Darren Tarshis, and the entire PER group at CU. We are grateful to the instructors at four outside institutions who administered the CUE in their courses.

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

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**Legend for Grading Rubric**

- **CUE scores** given in-class except C1. Response rates 75-100%.
- Error bars represent SE of the mean.

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**Comparison CUE at Multiple Institutions**

<table>
<thead>
<tr>
<th>Course</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>Gain (Post-Pre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU Pre-test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CU Freshmen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE2</td>
<td>±0.3</td>
<td>±0.9</td>
<td>2.62</td>
</tr>
<tr>
<td>IE3</td>
<td>±3.2</td>
<td>±3.4</td>
<td>0.28</td>
</tr>
<tr>
<td>C-IE</td>
<td>±4.3</td>
<td>±5.9</td>
<td>29.76</td>
</tr>
<tr>
<td>C1</td>
<td>±3.3</td>
<td>±7.5</td>
<td>15.93</td>
</tr>
</tbody>
</table>

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**Pre-test scores (7 questions out of 17) are about 30%, similar to freshmen just completing intro E&M (N=25).**

**Learning gains** (on those same 7 questions) are 20-30%.

**Pre-test scores for private liberal arts college (C-IE) are higher than those at other institutions, but learning gains are similar.**

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