



Tapping into Juniors' Understanding of E&M: Development of the CUE Assessment

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Overview

As part of a research-based effort to improve junior level E&M¹, we created a conceptual assessment to evaluate student understanding of upper-division E&M concepts -- **the Colorado Upper-Division Electrostatics (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: Griffiths² Chapter 1-6. Ten broad learning goals were developed by a **working group** of 10 faculty, including:

- | | |
|-------------------------|---|
| MATH/PHYSICS CONNECTION | ... achieve physical insight through the mathematics of a problem |
| VISUALIZE | ... sketch the physical parameters of a problem |
| COMMUNICATION | ... justify and explain their thinking and approach to a problem. |
| PROBLEM-SOLVING | ... choose and apply the appropriate problem-solving technique |



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

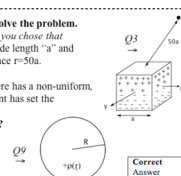
Q3. Give a brief outline of the EASIEST method that you would use to solve the problem.

Do not solve the problem, we just want to know the general strategy and why you chose that method. A solid, neutral non-conducting cube, centered on the origin, with side length "a" and charge density $\rho(x) = kx$. Find E (or V) outside, at point P, off-axis, at a distance $r=50a$.

Q9. You are given a non-conducting sphere, centered at the origin. The sphere has a non-uniform, positive and finite volume charge density $\rho(r)$. You notice that another student has set the reference point for V such that $V=0$ at the center of the sphere: $V(r=0)=0$.

- What would $V=0$ at $r=0$ imply about the sign of the potential at $r \rightarrow \infty$?
- $V(r \rightarrow \infty)$ is positive (+)
 - $V(r \rightarrow \infty)$ is negative (-)
 - $V(r \rightarrow \infty)$ is zero
 - It depends

Briefly explain your reasoning:



2 CUE questions

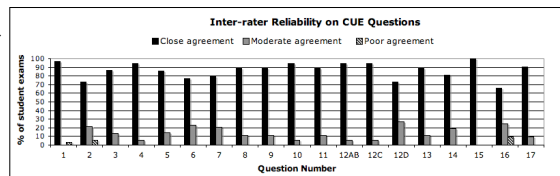
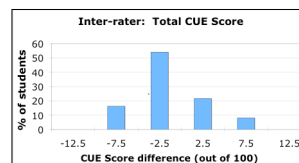
Correct Answer	3 points	Correct answer is multiple expansion using the dipole component. +4 point if say direct integration +2.5 for dipole only +0.5 for approximation or multiple +2 for multiple only +1 for dipole or +1 for approximation
Explanation	2 points	Full credit for saying dipole dominates because the observation point is far away. 1.5 points for "multiple because $r \gg a$ " +1 point if said that it's a dipole but give no further explanation +1 point if mention higher order multipoles, (but not a dipole) +0.5 for saying the integration is hard because it is off-axis. If they answered direct integration, full credit requires some mention of what the integral would look like or why they chose this method. +0.5 for a poor explanation of how they would go about it (e.g., writing down Coulomb's Law).

Grading rubric for Q3

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 $1.4\% \pm 0.6\%$ -- 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.



"Close" agreement is within $\pm 20\%$ (± 1 point on a 5 point question), "moderate" is within $\pm 20-50\%$ ($\pm 1-2.5$ points on a 5 point question) and "poor" is off by 50-100%.

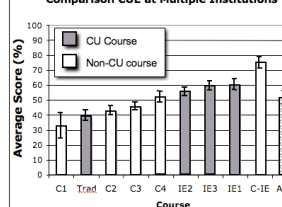
Results

- 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.

*All but IE2 are stat. significant

Pre/post test scores (matched by student).			
Code	Pre-test (%)	7-Q Post-Test (%)	Gain (Post-Pre)
CU Freshmen	30 \pm 3.0	N/A	N/A
IE2	30 \pm 2.3	51 \pm 2.9	21 \pm 2.8
IE3	33 \pm 3.2	61 \pm 3.4	28 \pm 3.0
C-IE	43 \pm 6.3	71 \pm 5.9	29 \pm 7.6
C1	33 \pm 5.3	47 \pm 12.5	15 \pm 9.3

Comparison CUE at Multiple Institutions



Trad = traditionally taught course at CU (N=26);
IE1-3 = transformed courses at CU (N=21, 48, 27);
C-IE = private liberal arts college using CU materials (N=12)
C1-4 = primarily lecture-based courses at other univs (N=6, 18, 52, 39).

"Comparison CUE scores" are a subset of the CUE given in common, due to changes in the exam over time. CUE given in-class except C1. Response rates 75-100%. Error bars represent SE of the mean.

- 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

Conclusions

- We have developed an open-ended assessment that taps students' mastery of some of the skills expected of a junior E&M student.
- See invited poster session for detailed analysis of student responses
- The assessment shows good reliability and validity 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

- S.V. Chasteen and S.J. Pollock *PERC Proc. 1064*, AIP, Syracuse, NY, 2008, p.91-94 and S.V. Chasteen and S. J. Pollock, *PERC Proceedings 2009*, submitted.
- D.J. Griffiths, *Introduction to Electrodynamics*, 3rd Ed. Upper Saddle River, New Jersey: Prentice Hall, 1999.

Use the CUE in your course!

All course materials & the CUE available at www.colorado.edu/sei/departments/physics.htm

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.