Cognitive Issues in Upper-Division E&M

The Utility of the Colorado Upper-Division Electrostatics Assessment (CUE)

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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

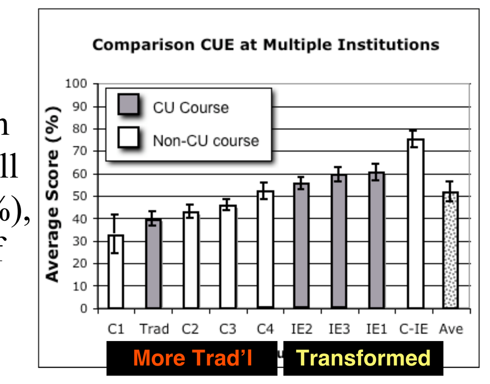
COMMUNICATION....................... justify and explain their thinking & approach.

PROBLEM-SOLVING..................... choose & apply appropriate techniques

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

Colorado Upper-Division Electrostatics (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 α=.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.



Trad = traditionally taught course, CU;
IE1-3 = transformed courses, CU;
C-IE = transformed course non-CU
C1-4 = primarily lecture-based, non-CU.

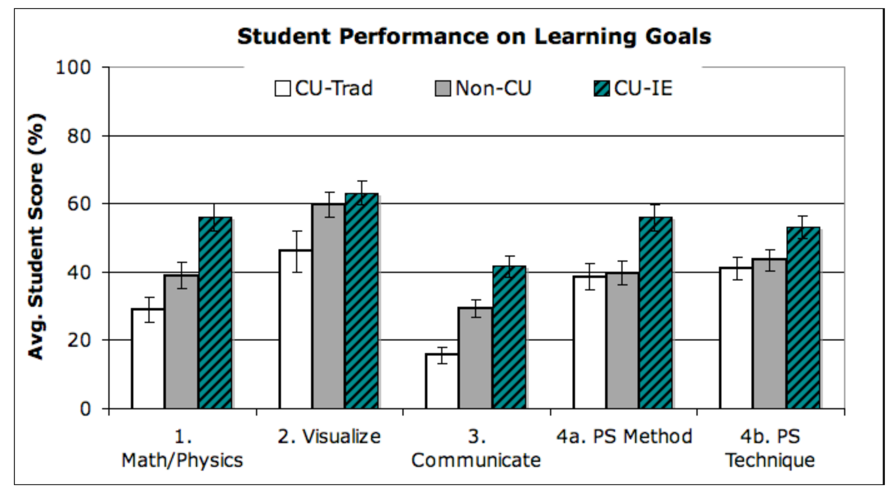
Student Performance on Learning Goals

Learning Goal	Description	# of Questions
1. Math/Physics	Physical meaning of equations	3
2. Visualization	Sketching, graphing	3
3. Communication	Explanations & justifications	9-11
4. Problem-Solving (a) Appropriate method (b) Techniques	 (a) Correct method for problem (b) Specific skills	 (a) 6-7 (b) 12-14

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

- The CUE distinguishes between pedagogical approaches, as well as possible institutional effects.
- CUE scores are moderately correlated with course grade (r=0.49, p<<0.01) at CU. We conclude the CUE is measuring aspects of student performance valued by faculty.
- Students in courses using **Transformed curriculum perform better** on all learning goals than those in other courses.

But, there is considerable room for progress in all areas.

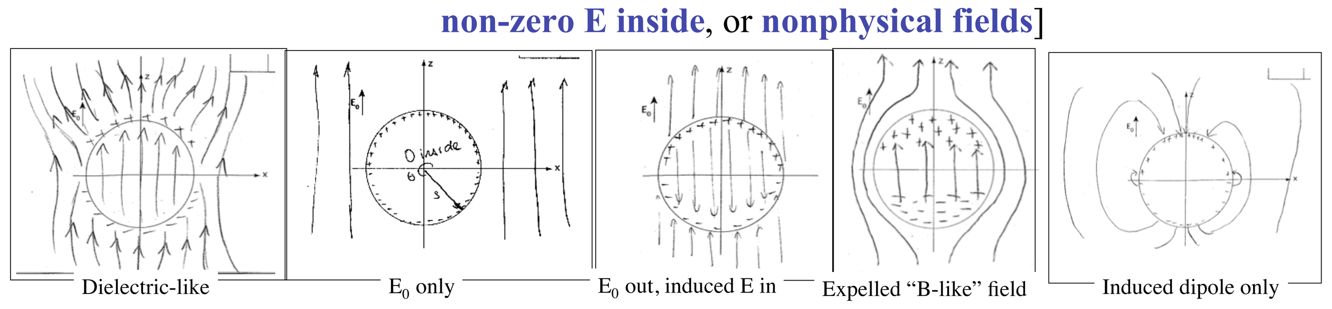


Non-CU is 2 courses (C3,C4, N=91). CU-IE is average of 3 CU IE courses (N=96). Total N=203

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 **E_0 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

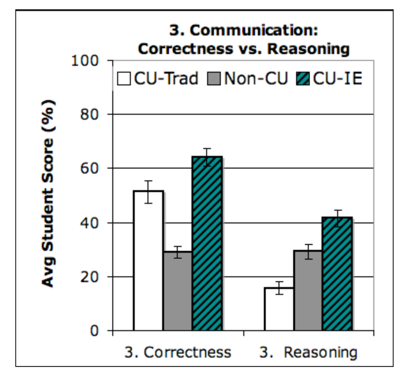
- Poor performance on this learning goal, particularly in traditionally taught courses
- **This skill is not supported in trad. instruction or generally valued on assessments**

- Correctness scored separately from reasoning on several questions. Example: Q9 (*potential far from a + sphere, with V(r=0)=0*): Students may choose the correct answer without proper or complete explanation.

E.g.: "When r=∞ is set to 0, V@r=0 is negative value"

"Change in V ∝ to - the integral of charge density"

"V = - ∫E•dl" (all received low scores 10% or less)



- **Students' explanations are often significantly lower than their ability to choose the right answer *but* improved ability in IE courses where reasoning emphasized**
- **Low scores by Trad students may be due to poor understanding, lack of training in explanatory skills, or low value placed on explanations ⇒ tough to interpret CUE.**

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)
  19% choose Multipole Expansion (despite the fact that field point is close to the cube).
- **E.g. Q3:** (*As above, with field point far and off-axis*) only 32% get full credit
  22% 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!')

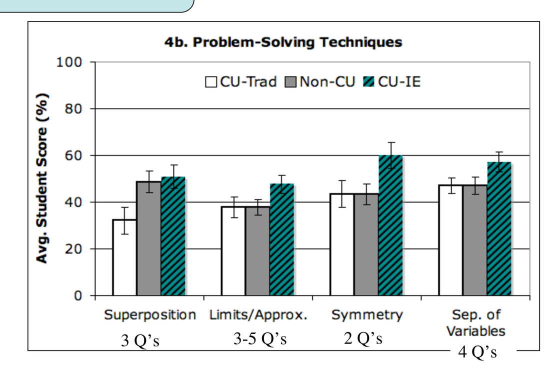
Problem Solving: Techniques & Skills

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 ∞ at disk. Others observe E goes to 0 at ∞, but do not answer the question of functional dependence.

Superposition

Eg. 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

[1] S.V. Chasteen and S.J. Pollock *PERC Proc. 1064*, AIP, Syracuse, NY, 2008, p 91-94.
[2] S. V. Chasteen and S. J. Pollock, *PERC Proceedings 2009*, submitted.
[3] D.J. Griffiths, Introduction to Electrodynamics, 3rd Ed. Upper Saddle River, New Jersey: Prentice Hall, 1999.
[4] Our work draws on previous efforts on curricular and assessment research at the upper division, including: C. Manogue et al, Paradigms in Physics: A New Upper Division Curriculum, *Am.J.Phys*. **69,** 978-990 (2001). Curricular materials online at www.physics.oregonstate.edu/portfolioswiki, B. Patton, Jackson by Inquiry, APS Forum on Education Newsletter, Summer 1996, and B. Patton and C. Crouch, Griffiths by Inquiry, Personal Communication, C. Singh, *Am. J. Phys*. **74**, 923 (2006).

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