Four Years of Transforming Upper-Division Physics

Results and Lessons Learned

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Abstract

Our department has committed substantial resources to improving our upper-division electricity and magnetism (E&M) course -- researching student learning, developing materials, and providing those resources to faculty teaching the course.

What have we learned -- about upper-division students, and about course transformations and faculty decision-making?
Methods

• Transformed first-semester of junior-level E&M starting in 2008

• Developed research-based materials with staff support and co-teaching
  ▶ Concept Tests / Clicker Questions
  ▶ Learning Goals
  ▶ Tutorials
  ▶ Modified Homework
  ▶ Student Difficulties

• Developed conceptual diagnostic, the CUE*

*Colorado Upper-Division Electrostatics assessment
Student-centered techniques improve conceptual understanding

Student learning gains on CUE higher in all research-based (PER) courses than in standard lecture-based (STND) courses

N=466
Student-centered techniques did not affect calculation success

- 5 typical exam problems given in common
- Students in PER courses similar to STND courses on calculation, but a bit better on some conceptual skills in problem-solving
Tutorials help student conceptual learning

Tutorials have a positive effect on student score on the conceptual exam (CUE), even when background variables taken into account.

\[
\text{OUTCOME} = b_0 + \left( \sum_{k=1}^{N} b_k \times \text{VAR}_k \right) + (b_{\text{TUT}} \times \text{TUTORIAL})
\]

<table>
<thead>
<tr>
<th>Population</th>
<th>CUE Model 1A</th>
<th>CUE Model 1B (with tutorials)</th>
<th>CUE Model 2A</th>
<th>CUE Model 2B (with tutorials)</th>
<th>Exam Model 1</th>
<th>Exam Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>156</td>
<td>156</td>
<td>87</td>
<td>87</td>
<td>192</td>
<td>103</td>
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<tr>
<td>Model based statistics</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Multiple R²</td>
<td>0.23</td>
<td>0.26</td>
<td>0.40</td>
<td>0.46</td>
<td>0.46</td>
<td>0.60</td>
</tr>
<tr>
<td>F statistic</td>
<td>47.24</td>
<td>27.08†</td>
<td>58.38</td>
<td>36.77 †</td>
<td>166.93</td>
<td>156.3</td>
</tr>
<tr>
<td>Residual standard error</td>
<td>15.26</td>
<td>15.04</td>
<td>13.01</td>
<td>12.41</td>
<td>0.77</td>
<td>0.66</td>
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<tr>
<td>Predictors</td>
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<tr>
<td>Phys GPA</td>
<td>0.48**</td>
<td>0.45**</td>
<td></td>
<td></td>
<td>0.68**</td>
<td>0.78**</td>
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<tr>
<td>BEMA</td>
<td></td>
<td></td>
<td>0.64**</td>
<td></td>
<td></td>
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<tr>
<td>Tutorials</td>
<td>0.17*</td>
<td></td>
<td>0.63**</td>
<td></td>
<td>0.24**</td>
<td></td>
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</tbody>
</table>
Other course elements are popular, but impact is uncertain

- Many elements increase student/instructor contact
- Instructors get more opportunity to get feedback on student difficulties, and can thus tailor instruction
Organized archives are important

Materials organized by topic and type of material. All modifiable. Instructors can pick and choose.

- Most instructors found archive takes time but is well organized.
- Most discussed the course with developers

“Just taking those materials and reading them isn’t the same thing [as talking to developers about the approach]”
– Instructor
Many Instructors Use and Appreciate Developed Materials

“[These materials] allow the interested person to start teaching a transformed course without the huge time investment that it might otherwise have required”
– Instructor

Tracked use of course materials since development.
✓+ exemplary
✓- minimal
✓ simply documented (when no data justify a +/-)

<table>
<thead>
<tr>
<th>TABLE 1. Sustainability of Course Structure</th>
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<tbody>
<tr>
<td>Semester</td>
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<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td>Learning Goals [Used in course prep?]</td>
</tr>
<tr>
<td>Clickers [Used, and used ideally?] (daily ave)</td>
</tr>
<tr>
<td>Tutorials [Offered?] (ave attendance)</td>
</tr>
<tr>
<td>Lectures [Interactive?] (ave attendance)</td>
</tr>
<tr>
<td>Group homework sessions [Offered?]</td>
</tr>
<tr>
<td>Whiteboards [Used often?]</td>
</tr>
<tr>
<td>Modified homework [Used?]</td>
</tr>
<tr>
<td>Documented student difficulties [Referred to?]</td>
</tr>
<tr>
<td>Implementation Fidelity (sum of ✓; +/- count ½)</td>
</tr>
</tbody>
</table>
Later Instructors Discontinue or Reduce Use of Materials

Development of course archives and evidence of success are necessary, but insufficient. Continuing faculty support is important.
Pedagogical Goals are Specific to Upper-Division

**Student identity** and **motivation** are more developed than lower-division. Many of alumni goals for the course matched those of our faculty.

**Learning Goals** are not the same as lower-division, and may (or may not) be shared among faculty. Our three main themes of learning goals were:

- Mathematical Sophistication
- Problem-Solving Expertise
- Developing as a Physicist
• Student-centered techniques are helpful in conceptual understanding and effective problem-solving (but not calculation)

• Student learning gains were still not as high as we would like. We need:
  ▶ More research on student difficulties
  ▶ More testing of pedagogical techniques
  ▶ A more radical approach, with less guided materials and more student-generated questions??
• Course results varied by implementation, such as:
  - Attention to specific upper-division student difficulties
  - Ideal (rather than minimal) use of materials
  - Student buy-in

• Instructors used materials, but later use was either non-ideal or materials were not used
  - Preparation of materials is insufficient -- continued support (and discussion of challenges) is required
References & Acknowledgements

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General


Assessment


Student Difficulties

