But Does It Last? Sustaining a Research-Based Curriculum in Upper-Division Electricity & Magnetism

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INTRODUCTION

At the University of Colorado at Boulder (CU), upper-division physics courses have historically been taught using a traditional lecture. The CU-Boulder Physics Department (assisted by funding from the CU Science Education Initiative; http://colorado.edu/sei) chose to introduce techniques that have been found to improve student learning in introductory physics courses – namely, interactive techniques such as concept tests and small-group tutorials, a focus on known student difficulties with the material, and an alignment between course materials and explicit expectations of student achievement. These techniques were applied to two core courses in the upper-division sequence: Electricity and Magnetism (E&M) and Quantum Mechanics. This paper focuses on the more mature transformation efforts in E&M.

There is evidence that student learning and enjoyment have increased in the course. But will these course materials – and their associated pedagogical approach – outlive the focused efforts of their developers? This is our current topic of study.

METHODS

The course. We have transformed the first semester of a two-semester junior-level sequence in electromagnetism. This course covers statics – chapters 1-6 of the text by D.J. Griffiths – and typically enrolls 30-50 students in a given semester.

The transformation process. Following the generic SEI model for course transformation, a postdoctoral Science Teaching Fellow (STF) was the main support for the course transformation. In collaboration with a faculty working group we developed a set of learning goals for the course. The STF observed a traditionally-taught semester of the course (TRAD) and reviewed relevant materials and research. In the first semester of the transformed course (RES1) the STF and a physics education research (PER) faculty developed course materials (available online), which were used and improved upon by subsequent instructors (Table 1).

The conceptual diagnostic. The Colorado Upper-Division Electrostatics (CUE) assessment consists of 17 open-ended questions addressing the course learning goals and consisting of written explanations, conceptual reasoning, sketching, and graphing, intended to be completed in a single lecture period. A 7-question pre-test was developed from a subset of the CUE. For more details, see previous publications.

WHAT WAS SUSTAINED?

Course Structure

We have tracked the use of course materials each semester since their first implementation (see Table 1). Use is rated as exemplary (√+) or minimal (√−) when justified by data collected by observation and instructor interviews; otherwise, use in any particular semester is simply documented (√).
TABLE 1. Sustainability of Course Structure

<table>
<thead>
<tr>
<th>Semester</th>
<th>RES1</th>
<th>RES2</th>
<th>RES3</th>
<th>RES4</th>
<th>RES5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instructor</td>
<td>Developers</td>
<td>PER1+STF</td>
<td>PER2+</td>
<td>Non-PER1</td>
</tr>
<tr>
<td>Learning Goals</td>
<td>[Used in course prep?]</td>
<td>✓+</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Clickers</td>
<td>[Used, and used ideally?]</td>
<td>(daily ave)</td>
<td>✓</td>
<td>(4.2)</td>
<td>✓+</td>
</tr>
<tr>
<td>Tutorials</td>
<td>[Offered?]</td>
<td>(ave attendance)</td>
<td>✓</td>
<td>(44%)</td>
<td>✓+</td>
</tr>
<tr>
<td>Lectures</td>
<td>[Interactive?]</td>
<td>(ave attendance)</td>
<td>✓</td>
<td>(94%)</td>
<td>✓+</td>
</tr>
<tr>
<td>Group homework sessions</td>
<td>[Offered?]</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Whiteboards</td>
<td>[Used often?]</td>
<td>✓+</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Modified homework</td>
<td>[Used?]</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Documented student difficulties</td>
<td>[Referred to?]</td>
<td>Not avail.</td>
<td>✓</td>
<td>✓+</td>
<td>✓+</td>
</tr>
<tr>
<td>Implementation Fidelity</td>
<td>(sum of ✓;/+/- count ½)</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>9.5</td>
</tr>
</tbody>
</table>

STF support in the research-based course decreased each semester, from full involvement (RES1, RES2), to weekly meetings (RES3, RES4), to sporadic discussion (RES5). Though implementation varied (e.g., attendance at lecture and tutorial and the number of clicker questions) only use of whiteboards and learning goals changed significantly in later semesters.

**Student Learning**

One aim in transforming this course was to improve student learning in several key areas (as measured by the CUE; Figure 1), such as the ability to visualize electric and magnetic fields, and to connect mathematics and physics at a sophisticated level.

![Conceptual Assessment (CUE)](image)

**FIGURE 1.** CUE results. Error bar represent ±1 SE of mean. “Gain” represents student absolute gains on the 7-questions on the Post-test which match the 7-question Pre-test; Gain (and SE) estimated for TRAD and RES1 (based on consistent Pre-test data in later semesters). Non-CU TRAD is an average of three courses at another large research university. Non-CU RES is the average of three courses at three institutions that used our research-based materials. Post-test N’s are as follows: CU TRAD(27), RES1-5 (20, 42, 27, 35, 59), Non-CU TRAD (221), Non-CU RES (31).

The CUE Post-Test and Gain scores are significantly higher in all research-based courses (RES) than in the TRAD courses. Because CU-TRAD was an anomalous course (offered as a split lecture), we administered the CUE at another large research university comparable to CU-Boulder (Non-CU-TRAD; a similar but higher ranked university). Student performance at Non-CU TRAD was higher than in CU-TRAD; however, it was still lower than in RES courses, suggesting that the research-based materials did indeed enhance student learning.

The high Post-Test scores in RES1 may be partially attributed to the somewhat higher GPA’s of students in that course compared to other RES courses. Otherwise, we see no clear relationship between student preparation or class size and Post-Test scores. Learning gains are slightly lower in RES2 and RES5, which will be discussed below. Additionally, 3 institutions used our research-based materials; their high scores on the CUE suggest that our course approach may be transferred successfully to other institutions, as well as between instructors.

**Student Experience**

While measurable learning gains are the main goal of course transformation, a positive student experience is also an important factor. A positive experience could enhance motivation and thus learning, and we hope that our physics students consider upper-division physics to be a joyful and intellectually stimulating activity, rather than a necessary drudgery on the way to a degree.

We first examined the Faculty Course Questionnaire (FCQ), administered by the university at the end of every term. Course and instructor ratings were higher in the RES courses compared to the TRAD course, but this difference can be accounted for by those instructors’ generally higher FCQ ratings in previous courses they’ve taught.

We also administered our own more detailed end-of-term survey. With some exceptions, students consistently found the aspects of the course (such as tutorials, homework, and lecture) enjoyable and useful, and well-connected to one another, with “homework” consistently receiving the highest utility ratings.
“Tutorials” varied in their reported utility, though overall response was positive for all semesters. “Whiteboards” were rated generally less useful for learning, and students’ reactions became more negative in later semesters; we hypothesize that whiteboard implementation could be improved.

Students in the RES courses spend more time on task: They reported spending more time per week on homework (7-9 hours) than in TRAD (3-4 hours) – which could be due to motivation and/or workload.

Student ratings were consistent across courses, with one notable exception. In RES2, students reported significantly less connection between in-class time, homework, and exams; lower utility of tutorials; lower enjoyment of pure lecture and tutorials; less comfort asking questions during class; and less satisfaction and learning in the course overall. These results are discussed below.

**WHAT AIDS TRANSFER?**

Based on our observations of the course, and detailed interviews with instructors, we report below on some themes that appear to have supported (or hampered) the successful transfer of the course between instructors, many of which echo the literature on sustainable innovations.9,10,11

**Departmental Culture & Support.** Lasting change is not created by lone visionaries, but by committed departments working together to create programs suited to the local needs.11 The physics department was deeply involved in the current effort, through faculty working groups and enthusiastic support by the chair and associate chair. Through this support, we were able to arrange for the course to be taught for several years by faculty likely to continue the transformation. Our hope was that the transformations would become part of the departmental culture without top-down requirements. Additionally, the physics department has long been steeped in educational transformation, resulting in broad-based buy-in of PER-techniques, such as clickers. This creates an overall friendly climate for educational innovations.

**Team Teaching.** The department also provided the financial support necessary to allow team teaching in one semester of the course (RES2). An award-winning instructor (PER-2) was paired with a non-PER instructor (Non-PER-1), who was friendly to PER techniques and might be considered to be in the “zone of proximal development;” already a clicker user, he reported an increase in his use of fully interactive teaching, such as asking for students to defend their clicker votes. However, he felt that this improvement in his teaching was independent of the course transformation: Thus, team-teaching may have been a valuable part of transforming the instructor, but not the course. It may even have been unfavorable for some instructors: PER-2 reported less investment in the course due to the presence of the co-instructor.

**Staff & Developers.** In addition to departmental support, staff were dedicated to the transformations. Instructors felt that this staff support was crucial in creation and documentation of the new materials, and reducing some work burden of the course. The STF provided the legwork to develop the original transformations, create and sustain the course archives, and document the impact of the transformations through research and observation (e.g. CUE). Additionally, undergraduates12 assisted with development and facilitation of the tutorials.

**Co-Seminar Course.** The tutorials have been institutionalized as an optional 1-credit co-seminar. Students indicate that this single credit is not an important motivating factor in student attendance. However, the co-seminar has the benefit of legitimizing the tutorials as a course so that (a) students may enroll in it, and (b) instructors must commit to offering (or not) several months prior to the start of the course. This provides an opportunity for the STF or other PER instructors to approach the new instructor in advance, effectively pre-selling the idea of course innovation and getting instructors involved early, as recommended by Tobias. Tutorials, as well as homework-help sessions, were often favorably cited by instructors as giving them opportunities to see students’ difficulties in a way not usually possible.

**Instructors’ Positive Experience & Perception.** Interviews with instructors reveal an overwhelmingly positive response to the materials; all expressed satisfaction with using the transformed material, and said that they would use the materials again, mentioning improved student learning (though not CUE data) or student experience in the course, positive feedback from students, improved knowledge on their part of where students were struggling, and greater impact for the same amount of preparation time. Three out of the five also spontaneously mentioned their personal enjoyment of elements of the transformed course: “Next time you need somebody else to do it, don’t hesitate to call!” [Non-PER-1]. Such enthusiasm can be leveraged for word-of-mouth dissemination.

**Course Archive.** Faculty take pride in creative course planning and implementation. Thus, they indicated that they prefer materials organized so that they can choose relevant materials à la carte, and modify them to taste. We have done this by providing a downloadable zipped folder1 of all course materials (organized both by topic and material type, with self-explanatory titles), and giving this electronic archive.
to each subsequent instructor before the new semester, along with a brief tour. Instructors generally report that these materials take substantial time to use (especially in the beginning), but are well-organized and extremely beneficial: “They allow the interested person to start teaching a transformed course without the huge time investment that it might otherwise have required,” said one. Instructors report that they received more material than they would have in the past, allowing them to be guided by more than just personal opinion. That said, instructors used their best judgment in implementing materials and organizing the course framework, which is largely appropriate as we have no research base for making particular suggestions. Lastly, informal discussions with the developers may be valuable in implementing the course: “Just taking those materials and reading them isn’t the same thing [as talking to developers about the approach]” reported one instructor, though Non-PER3 reported that the materials stood on their own. While these instructors implicitly agreed with our learning goals, material use doesn’t necessarily imply buy-in of the goals or pedagogy.

**Less Successful Transfer.** RES2 and RES5 had the lowest CUE learning gains, and also had the lowest fidelity to the course approach (see “implementation fidelity” in Table 1). Students in RES2 had more negative attitudes than those in other semesters. Student motivation and buy-in may have been low, as some complained that the lectures were “too easy” to prepare them for the homework, and too much time was spent on clicker questions. The main lecturer (PER2) is an award-winning instructor, but tends to teach lower-division courses. He used far more clicker questions than in other semesters, and was the only instructor who did not find previous instructors’ lecture notes useful. He also admitted to being unusually busy that term, and thus less invested in the course than he might have been. We hypothesize that this term suffered from some fragmentation (due to co-teaching and instructor inattention). It is possible that this instructor was following his lower-division practices and beliefs too closely, rather than attending to the needs of these upper-division physics students.

Students in RES5, taught by a popular upper-division lecturer, had positive attitudes but lower learning gains than other courses. This instructor used the fewest clicker questions of any of the RES courses (often only one at the beginning and one at the end of lecture), and tended towards dynamic lecture with clicker questions to apply lecture material. This instructor had previously been mentored in PER techniques in a similar co-taught course transformation in Quantum. However, in E&M he received no STF support, did not discuss the course with developers, and spent less time preparing than other instructors, perhaps indicating a shift towards a more traditional teaching approach (and hence, lower student learning).

**CONCLUSIONS**

Departmental and staff support was important in generating and maintaining the use of new course materials and student learning gains for 5 semesters of this upper-division course. However, the materials serve as support for a new teaching approach, and do not themselves comprise a successful course transformation. The instructor must invest substantial time and energy both to understand the philosophy of the course approach, and to be immersed in the students’ difficulties with the material. Interpersonal relationships, fruitful discussions with colleagues, and a positive experience may be key for instructors to incorporate developed materials into the personal intellectual endeavor of upper-division teaching.

**ACKNOWLEDGEMENTS**

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**REFERENCES**

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