

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

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Abstract. We report on the process and outcomes from a four-year, eight-semester project to develop, establish, and maintain a new course approach in junior-level electricity and magnetism (E&M). Almost all developed materials (i.e., clicker questions, tutorials, homework, and student difficulties) were used successfully by several subsequent instructors, indicating a high rate of sustainability over time and between instructors. We describe the factors related to successful transfer and to decisions not to adopt the materials, based on observations, instructor interviews, and student data.

Keywords: physics education research, course reform, electricity and magnetism, assessment

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INTRODUCTION

At the University of Colorado at Boulder (CU), upper-division physics courses have historically been taught using 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[1] – explicit learning goals, interactive techniques such as concept tests and small-group tutorials, and a focus on known student difficulties with the material. We have evidence that student learning and enjoyment have increased in the course[2]. But will these course materials – and their associated pedagogical approach – outlive the focused efforts of their developers? This was the topic of the current study.

METHODS

The transformation process. We have transformed the first semester of a two-semester junior-level E&M sequence. This course covers electro- and magneto-statics and typically enrolls 25-50 students in a given semester. Following the Science Education Initiative (SEI) model for course transformation[2], a postdoctoral Science Teaching Fellow (STF) was the main support for the change. In collaboration with a faculty working group we developed learning goals for the course. The STF observed a traditionally-taught semester of the course (TRAD0) 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[3]), which were used and improved by subsequent instructors (Table 1).

The conceptual diagnostic. The Colorado Upper-Division Electrostatics (CUE) diagnostic consists of 17 open-ended questions requiring written explanations, conceptual reasoning, sketching, and graphing, intended to be completed in a lecture period. A 7-question pre-test was developed from a subset of the CUE; see previous publications.[2]

WHAT WAS SUSTAINED?

Course Structure

We have tracked the use of course materials each semester since their first implementation (see Table 1). 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 in lecture and optional tutorials), and the number of clicker questions) only use of whiteboards and learning goals changed significantly in later semesters of the transformed course. After RES5, however, the course was taught traditionally twice (TRAD1 and TRAD2), discussed later.

One goal of the transformations was to improve student learning in several key areas. To compare the transformed courses to traditional instruction, we have administered the CUE at CU and elsewhere. Taking each student as a data point (N=488; Table 1), the average CUE score is higher in the transformed courses (58.2 ± 1.4 , 5 courses at CU, 3 non-CU; 189 students) than in standard courses (44.6 ± 1.6 , 2 courses at CU, 6 non-CU; 299 students, $p < 0.001$). The

TABLE 1. Sustainability of Course Structure

Semester	TRAD0	RES1	RES2	RES3	RES4	RES5	TRAD 2
Instructor →	Non-PER1*	PER1 +	PER2* +	Non-PER2*	Non-PER3	Non-PER4	Non-PER5*
* = tenured		STF	Non-PER2*				
Learning Goals [Used to prep?]	N/A	✓+	✓	✓+	✓	0	0
Clickers [Ideal use? [4]] (<i>ave/day</i>)	N/A	✓+ (3.5)	✓ (4.2)	✓+ (3.1)	✓+ (3.3)	✓- (2.5)	✓- (†)
Tutorials [Offered?] (<i>ave attend.</i>)	N/A	✓ (44%)	✓ (30%)	✓ (42%)	✓ (36%)	✓ (35%)	0
Lecture [Interactive?] (<i>ave attend.</i>)	0 (73%)	✓+ (94%)	✓+ (86%)	✓+ (77%)	✓+ (77%)	✓ (74%)	✓- (54%)
Group HW sess. [Offered?]	0	✓	✓	✓	✓	✓	✓-
Whiteboards [Used?]	N/A	✓+	✓-	✓	✓	0	0
Modified HW [Used?]	N/A	✓	✓	✓	✓	✓	✓-
Documented student difficulties [Referred to?]	N/A	N/A	✓	✓+	✓+	✓-	✓-
Implementation Fidelity (sum of ✓; +/- count ½)	N/A	9	8	10	9.5	5	2.5
CUE post-test score (%)	39.4 ± 3.2	60.1 ± 3.6	55.3 ± 2.4	59.2 ± 2.9	55.5 ± 2.9	53.2 ± 8.2	46.2 ± 4.2
# students took CUE / course N	27 / 40	20 / 20	42 / 48	27 / 35	35 / 56	34 / 46	22 / 41

TABLE 1. Use is rated as exemplary (✓+) or minimal (✓-) when justified by data collected by observation and instructor interviews; otherwise, use is documented as present (✓) or absent (0). Implementation fidelity is an ordinal, rather than interval, measure. TRAD1 (taught by Non-PER 1) is not reported: This course did not use course materials and CUE data is not available. CUE score is based on a subset of the test consisting of questions given in common across all semesters. The N of students taking the CUE is lower for TRAD0 and TRAD2, but in both cases represent the higher-performing students in the class (compared by course grade). †TRAD2 used clickers only early in semester and in review classes (13 out of 44 classes).

Average CUE score in CU-TRAD courses (43.0 ± 2.8) is similar to non-CU TRAD courses (45.1 ± 3.8), and thus is taken as representative. Average CUE score for CU-RES courses is higher: 56.2 ± 4.3 . Learning gains[5] are slightly lower in RES2 & RES5 (18.2 ± 2.9 & 20.7 ± 1.3) than other RES courses (27.6 ± 3.0).

We investigated student demographics, since CUE score is strongly affected by student background[6]. All eight semesters are similar in terms of student GPA in previous courses, with two exceptions: The average pre-requisite GPA is marginally higher in RES1 (3.2 ± 0.1) than in other courses (3.0 to 3.1 ± 0.1), and marginally lower in TRAD2 (2.9 ± 0.1), which is also characterized by lower pre-requisite math GPAs.

Regardless of institution, CUE scores are lower in TRAD courses than in RES courses suggesting that the research-based materials enhance student learning[7]. Additionally, CUE scores are maintained over subsequent iterations of the transformed course. The high CUE scores of the 3 external institutions that used our materials (67 ± 5.7) 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 measure of success. We examined the course evaluations administered by

the university every term. Course and instructor ratings were higher in the RES courses compared to the TRAD courses, but this difference covaries with those instructors' ratings in previous courses. We also administered our own end-of-term survey. Students consistently found tutorials, homework, and clicker-based 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; we hypothesize that whiteboard implementation could be improved. Students in RES courses spend more time on task: They reported spending more time on the course as a whole (10-12 hours/week, except RES5 at 7-9 hours) and on homework, than in TRAD courses (7-9 hours), and attendance is higher in all RES courses.

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.

WHAT AIDS TRANSFER?

Based on our observations of the course, and detailed interviews with instructors during and after

instruction by two authors (SVC and REP), we report below on some themes that we believe supported (or hampered) the successful transfer of the course between instructors, many of which echo the literature on sustainable innovations [8,9,10].

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 [10]. 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 department has long been steeped in educational reform, 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 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 experienced and interested in PER techniques; already a clicker user, he reported an increase in his use of fully interactive teaching, such as asking for students to defend their clicker vote. 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 sharing of responsibility.

Staff & Developers. In addition to departmental support, staff were dedicated to the transformations. Instructors felt staff support was crucial in creation and documentation of the new materials, and reducing some of the course work burden. The STF helped develop the original transformations, create and sustain course archives, and document the impact of the transformations through research and observation (e.g. CUE). Additionally, undergraduates [11] 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 attendance. However, the co-seminar legitimizes tutorials as a course that (a) students may enroll in, 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[10] Tutorials and 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 who used the transformed materials reveal an overwhelmingly positive response; all expressed satisfaction with the materials, and said that they would use them again, mentioning their observations of improved student learning in the course (but not CUE data), positive feedback from students, improved knowledge on their part of where students were struggling, and greater impact for the same or slightly more 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. Our experience is that faculty take pride in creative course planning and implementation. Thus, faculty indicated that they prefer materials organized so that they can choose relevant materials à la carte, and modify them to taste. We did this by providing a folder[3] of course materials (organized both by topic and material type, with self-explanatory titles), and giving this 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; appropriately, as we have no research base for making particular suggestions. Informal discussions with the developers may also be valuable: "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.

LESS SUCCESSFUL TRANSFER

Why did RES2 and RES5 have the lowest CUE learning *gains* of RES courses, and the lowest fidelity to the course approach (Table 1)? Student motivation and buy-in in RES2 may have been low; these students had more negative attitudes than those in other

semesters, some complained that the lectures were “too easy” to prepare them for the homework, and too much time was spent on clicker questions. Additionally, more engineering physics majors took this course than other semesters; a population with perhaps different expectations than physics majors. The main lecturer 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).

Later instructors did not use the course materials at all (TRAD1) or minimally (TRAD2). Based on interviews with one instructor (TRAD2), we hypothesize that these two instructors were (a) less interested in interactive techniques, particularly at the upper-division, and (b) had previously taught the course several times and thus were reluctant to invest the time to incorporate new materials. Our inclination to “put the materials out there” and hope that instructors will use them is perhaps naïve, especially considering recent work on faculty incorporation of PER techniques [9]. Continued faculty support – both in terms of staff time (e.g., to run tutorials), and discussions (e.g., to find out faculty’s teaching concerns, and how we might work together to address them, using course materials or not) may be required. Targeting junior faculty (who lack developed materials and are eager for help), or experienced faculty interested in a new teaching approach, might be the most fruitful methods. (We note that Non-PER-2 had previously developed course materials, but was interested in using the transformed approach when it became available, due to pedagogical philosophy). Considering the strong correlation between use of the

transformed materials and CUE scores, it is important to learn how best to work with faculty in this regard.

CONCLUSIONS

How do instructors incorporate developed materials into the personal intellectual endeavor of upper-division teaching? Lack of previously developed material (on the part of the instructor), as well as interest in trying something new, may be key aspects of a faculty decision to use PER materials. Departmental and staff support was important in generating and maintaining the use of new course materials and student learning gains for 5 out of 7 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 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 appear to be common characteristics of instructors who most successfully incorporate developed materials into their own course.

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