A Thoughtful Approach to Instruction: Course Transformation for the Rest of Us

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Faculty often wish to devote time and resources to improve a course to be more in line with principles of how people learn but are not sure of the best path to follow. We present our tested approach to research-based course transformation, including development of learning goals, instructional materials based on student difficulties, and assessment to see whether the approach worked. This method of course transformation has measurably improved student learning in several courses, and we present one such course as a case study—an upper-division physics course. We relied on various support personnel, including undergraduates, to help instigate and maintain the course transformations, and we describe the departmental and institutional factors that are important for successful transformation and sustainability. This model, and the lessons we have learned through its implementation, may serve as a guide for faculty interested in trying a new approach in their own courses.

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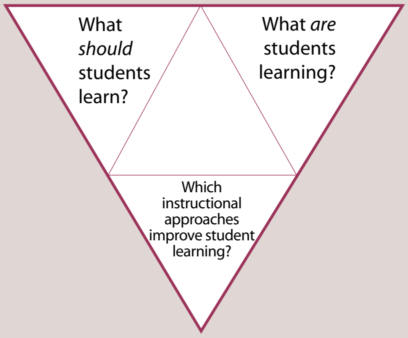
As a community, we must ask ourselves: How successfully are we educating all students in science? (Wieman and Perkins 2005). The data indicate that we are not where we want to be; too many undergraduates in our courses are not learning the science (Handelsman et al. 2004). We are fortunate, however, in that we have access to a growing body of research on effective ways to teach science (e.g., Bransford, Brown, and Cocking 2000; Cummings et al. 1999; Hake 1998; McDermott and Redish 1999; Redish 2003). This research tells us how we can improve student learning—through student-centered activities such as inquiry, peer instruction, and group work, plus an added focus on problem-solving ability, concepts, and connections to the real world. But most undergraduate science courses are taught by lecture (National Science Foundation 1996). How does a teacher use these interactive techniques effectively to restructure an existing course?

Our mission at the University of Colorado (CU) and University of British Columbia Science Education Initiative (SEI; *http://colorado.edu/sei*) is to address this gap and to support and facilitate faculty in using research and assessment to guide the way we teach (see Figure 1). We have worked across 11 departments in two institutions to develop and refine a model of research-based course transformation. Here, we present that model and hope that our experience is informative for instructors wanting to systematically transform a course.

FIGURE 1

The SEI model of course transformation.



The transformation process

We have identified several important steps in successful course transformation (see Table 1), including observing and discussing the course prior to teaching, making changes to the course, assessing the success of the transformation, and ensuring that those changes endure (for more documents on course transformation, see *www.cwsei.ubc.ca/resources/other.htm#transform*). We advocate the use and practice of education research as part of the process of course change, often involving additional support outside the primary instructor. As a concrete example, we focus here on our efforts to transform junior level Electricity & Magnetism I (E&M I; Chasteen and Pollock 2009).

In our experience, the entire transformation of a course requires two semesters at minimum: one for creating draft materials and another for revision. These semesters are preferably preceded by a planning term.

The first step is to involve key faculty and/or administrators. In our work, the department faculty had voted to seek funding from the SEI to participate in these course transformations, and we had significant support from the department chairs. The next step was to consult faculty who had taught the course in past years. In these individual interviews and informal biweekly brown-bag meetings, we began by discussing the course in general, such as where it fit into the departmental curriculum and what the perceived opportunities for improvement were. After a few meetings of orientation, we began to tackle the question of what students need to be able to do by the end of the course—the learning goals.

Learning goals or outcomes

What is a learning goal?

Learning goals define operationally what students should be able to do if they successfully learn the material; such goals have been used successfully in many contexts (e.g., Sagendorf, Noyd, and Morris 2009). We have found it useful to consider both course-level and topic-level learning goals. A course-level goal might be as follows: Students should be able to choose and apply the problem-solving technique appropriate to a particular problem, including use of approximations, symmetries, and integration.

The course-level goals are broad and generally not related to particular course content. A topic-level goal is more specific and a step toward achieving one or more of the course-level goals (e.g., Students should be able to recognize where separation of variables is applicable, and to apply the physics and symmetry of a problem to state appropriate boundary conditions.).

These are each more specific and testable than what one usually sees on a syllabus. All learning goals, assessments, and other materials for this course are available at *http://colorado.edu/sei*.

Why learning goals?

Learning goals effectively define what it means to "understand" in the context of this course and provide a vehicle for faculty to more effectively communicate to students and to other faculty what students are ex-

TABLE 1

Central features of course transformation.

Steps	Description	Tasks
Project scope	What do we want to accomplish?	Facilitate meetings of faculty working group.
Course- and topic-level learning goals	What do we want students to learn (e.g., content, skills, habits-of-mind, attitudes)?	Facilitate meetings of faculty working group.
Document student thinking	How do students think about the material of the course, and what do they know coming in?	Do literature review. Observe course before and after transformation. Interview students.
Teaching methods	How will we help them learn the material?	Create course materials consistent with research on how people learn. Select teaching practices and course structures.
Assessment	How do we know if students achieved the learning goals?	Exams Conceptual assessments Pre- and postsurveys Student interviews
Materials archived	How will others find/use what we've done?	Organize materials locally and online.
Plan for sustainability	How will the fruits of our labors be adopted and/or adapted by others?	Interact with faculty and administrators prior to and following transformation; implement support strategies such as coteaching.

pected to learn. It is also clearer what should be included on assessments (exams, quizzes). The process of creating goals has also significantly increased faculty communication and discussion about what is important in our undergraduate education.

From topics to learning goals

It is a challenge to transition from a list of topics to measurable goals that are focused on meaningful student learning. Ideally, goals should be dialed to the right level of cognitive sophistication (i.e., not regurgitation of facts; Bloom and Krathwohl 1956; Anderson and Krathwohl 2001) and be clearly related to what students would see as valuable things to learn. Several resources exist to assist in articulating learning goals (e.g., *www.cwsei.ubc.ca/resources/learn_goals.htm*).

For E&M I, a working group of about 10 faculty members, most of whom had taught the course previously, met six times in an effort to assure that the resulting goals represented broad faculty input and consensus. The involvement of instructors who teach courses before or after the course in question, or in related departments, helps in the identification of problem spots and faculty expectations and facilitates the alignment of courses within and between departments.

It is unrealistic to expect faculty to come to a consensus on 100% of the topic goals; however, we recommend and have found that faculty can typically agree on 75% of the goals, leaving 25% for faculty to put their own "fingerprint" on the course. One concern posed by faculty is that learning goals take the creativity and flexibility out of teaching. However, the goals do not dictate the curriculum; pedagogical structure; or, most important, how faculty members interact with their students. Nevertheless, it is seldom a trivial task for a group of faculty to arrive at a consensus on learning goals for a course.

Turn the microscope on your students

What we want to advocate in this paper is a scholarly approach to course transformation in the sciences. Quite often, faculty use trial and error (Boice 1992) or personal learning experiences rather than research literature or tested methods to create or revise a course. Many faculty are excited to try new things, such as group work or adding clicker questions to their courses. This is not a bad thing in itself, but it is not likely to solve all the problems in the course because faculty seldom know what all those problems are (Redish 2003). Faculty can discover how students are thinking about the content and identify common difficulties by

- searching the literature for education research on the course content,
- observing students during class and listening to their conversations during discussions,
- keeping field notes of student questions in class or during office hours,
- reading through homework and exams and documenting common errors and difficulties,
- administering and evaluating a short (content) survey or two-minute paper(s) in class, and
- interviewing students.

In E&M I, we observed a traditionally taught class, ran group sessions to help students with homework, and interviewed students for a semester before the transformed class was taught. During the course transformations, the class was observed and videotaped, and we documented student difficulties and questions during class, on exams and homework, and during optional tutorial and recitation sections. Note that all collection of student data for research purposes was subject to Institutional Review Board approval—an important consideration in gathering data for research purposes. Students completed consent forms for participating in aspects of the research not considered part of normal class operations, such as surveys and interviews.

Change the course

New curriculum and teaching practices are the meat of what many consider course transformation, but ideally these changes come after substantive work, being built on the strong foundation of broad faculty involvement, learning goals, and observations of student thinking and difficulties.

There are many models of how to create course materials (e.g., Chasteen and Pollock 2009; McKagan, Perkins, and Wieman 2007). The most important thing is that the course be aligned with the learning goals already established and that the results of student observations be used to inform the changes. You can use or adapt curriculum or materials and techniques developed by the education community (Bransford, Brown, and Cocking 2000; Mayer 2008; Redish 2003) or by other faculty members. Familiarity with research-based pedagogical approaches (Bransford, Brown, and Cocking 2000; Handelsman et al. 2004; Redish 2003), as well as student difficulties in the content area, can help inspire effective changes.

In many ways our new E&M I course was not a dramatic departure from traditional courses. The primary classroom activity was interactive lecture, unlike other models that have switched completely to small-group work (Manogue and Krane 2003; Patton 1996). However, many aspects of the course were carefully designed to fulfill the learning goals of the course, primarily through the methods of active engagement, making the physics explicit, and requiring students to articulate their reasoning. Optional sessions were used for additional group work. See Table 2 for details.

Though Table 2 lists the course elements, we emphasize that this was not simply an exercise in development of curricular materials, but of a new pedagogical structure to the class, supported by materials—a type of change that may be more lasting (Tobias 1992), though challenging to convey to new instructors. Assessment should be given high priority; it is a powerful tool for convincing your colleagues (Turpen and Finkelstein 2008)—and yourself—that the new course is a good thing. In addition, results of assessments provide valuable feedback, identifying where additional work is needed to achieve the desired learning. Following are some references on how to write good assessments (Adams and Wieman 2010; American Educational Research Association 1999; Committee on the Foundations of Assessment 2001; *www.flaguide.org/*; *http://testing.byu.edu/info/handbooks.php*).

Did it work?

To determine whether the changes we made to the course were effective, we compared outcomes from a total of 15 courses at CU and elsewhere, including eight semesters taught using the transformed course materials (five of which were at CU). Non-CU courses were drawn from a variety of institutions.

At CU, the Traditional course (CU-TRAD) was taught by a theoretical physicist who tends to teach upper-division courses using traditional lecture, and the transformed Physics Education Research (PER) courses (CU-PER1 through CU-PER5) were taught first by the curriculum developer (a member of the PER group), then by another PER instructor with a non-PER coteacher, then by the non-PER instructor alone. Thus, these data allow us to compare effects of curriculum and instructor.

Students were very positive about the PER-transformed courses, as judged by end-of-term surveys. Attendance in lecture was higher, on average, for the PER-transformed courses; students were more likely to come to homework help sessions and reported spending more time on the homework, and about 50% of the class, on average, attended the optional tutorial sessions. If nothing else, students in the PER-transformed courses spent more time on task.

Three typical electrostatics exam problems were given to students in three of the courses (TRAD, CU-PER1, and CU-PER3), graded on a common rubric, and used to create a composite "exam" score. Because these traditional questions do not explicitly assess progress on many of the learning goals, we developed a conceptual survey, the Colorado Upper-Division Electrostatics (CUE) Diagnostic (Chasteen and Pollock 2009). The CUE is a 17-item test consisting of written explanations, sketching, and graphing. It was developed from the learning goals and faculty input and validated through student interviews and item analysis.

Students in the transformed course achieved higher scores on the CUE assessment and on certain elements of the traditional assessments (particularly reasoning and explanations). Figure 2 shows these data: The CUE score consists of those questions given in common between courses, as the instrument changed over time. The "Trad'l Exam" score represents a composite exam score as described above. The dotted line represents the nonweighted average of the CUE over courses: These differences between Traditional and PER courses (at CU and elsewhere) are statistically significant. Thus, by both measures, the course transformations were highly successful. More information can be found in our upcoming publication (Chasteen et al. 2011).

We find that noneducation-research faculty teaching successive semesters of the course have implemented most aspects of the PER-transformed course; they find the materials useful in their instruction and are particularly appreciative of the adaptability of materials (see Chasteen et al. 2010). As shown in Figure 2, there is a high rate of sustainability of CUE scores from instructor to instructor.

"How do I do all this?" Models of transformation

It can be difficult to incorporate an extensive effort at course improve-

TABLE 2

Course elements in Electricity & Magnetism I.

Course element	Details
Interactive lecture	"Mini" lectures interspersed with clicker questions with peer discussions, whole-class conversation, simulations, student work on small whiteboards, short writing assignments, and kinesthetic activities (OSU Paradigms).
Additional organized activities	Weekly tutorials (based on work by Patton 1996, Patton and Crouch, personal communication, 2008; Manogue and Krane 2003) reinforced and expanded on topics in lecture and prepared students for homework and weekly homework help sessions, optional but well-attended.
Homework	Creation of "bank" of homework problems that required students to connect abstract problems to real-world situations, draw on common problem-solving tools, explain reasoning, or make sense of the answer.
Assessments	Traditional exams Research-based conceptual posttest (e.g., CUE) Student feedback on informal surveys Student attitudes as measured by the Colorado Learning Attitudes About Science Survey (Adams et al. 2006)

Note: CUE = Colorado Upper-Division Electrostatics assessment; OSU = Oregon State University.

ment with the daily responsibilities of a faculty member. We find that this task is best approached with the help of the department and other individuals in the institution. Methods to manage this transformation include the following:

- Find a support system (e.g., other faculty) for advice and/or implementation.
- Seek departmental support (e.g., release from teaching time prior to the transformation, undergraduate assistants, or additional TAs).
- Hire a facilitator or support person, such as a science teaching fellow (STF)—a temporary postdoc with a PhD in the discipline and interest/experience in education research and course transformation (at CU, an STF was hired by the Physics Department with funds from the SEI).
- Create a teaching group or learning circle (Lynd-Balta et al. 2006), where several faculty support and observe each others' teaching.

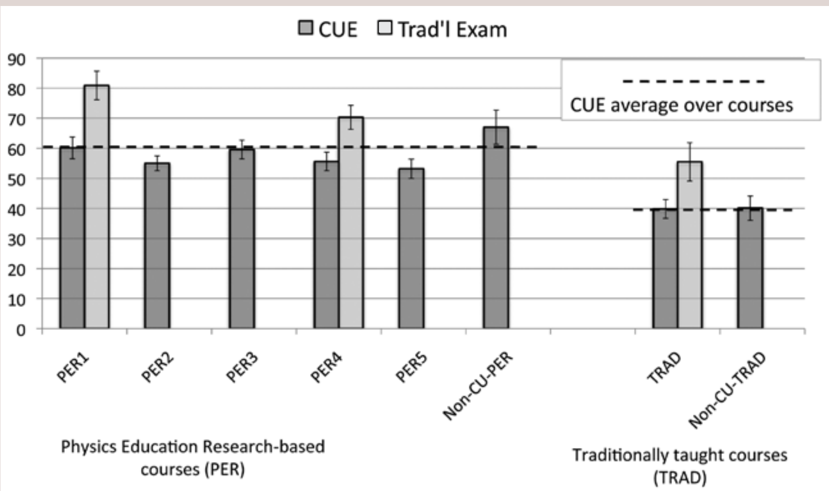
An external support person, such as an STF, can be immensely valuable in course transformation (please see our website at *www.cwsei.ubc.ca/departments* for more information on the SEI model). We particularly note the vital role of the STF in identifying student thinking and difficulties, assessment, and archiving materials. Other faculty members can also provide helpful feedback and ideas (see also the section on team teaching).

Even a solo instructor can make substantial progress by observing classes taught by other instructors—especially those known for their teaching innovations, visiting the course as it is being taught prior to the transformations, and listening to students.

FIGURE 2

Student results on traditional assessments (exams) and conceptual assessment (CUE) in TRAD and PER-based courses at CU and elsewhere (*N* = 466).

Traditionally taught courses include CU-TRAD (*N* = 41) at our institution and Non-CU-TRAD. Non-CU-TRAD represents the average of CUE scores from six public and private institutions, taking each course as one data point (*N* = 48, 35, 6, 18, 5, 138). PER-based courses include those at our institution—CU-PER1 through CU-PER5 (*N* = 20, 42, 27, 35, 34)—and Non-CU-PER. Non-CU-PER represents the average of three courses at other public and private institutions (*N* = 5, 12, 14), taking each course as one data point. Those non-CU courses labeled as *PER* used at least two of our developed course elements (typically clickers and tutorials). Error bars are +/− 1 standard error of the mean; where several courses are averaged together, the standard errors of individual courses are combined in quadrature. CU = University of Colorado; CUE = Colorado Upper-Division Electrostatics; TRAD = traditional; PER = Physics Education Research.



These practices are then combined with instructor reflections on their own teaching practice and information from the research literature.

Last, good undergraduates can provide a surprising amount of assistance in course transformation. In our transformations, we made use of two undergraduates (a Noyce fellow and a learning assistant; see Otero et al. 2006), who assisted with writing clicker questions on the basis of their experiences in the class and with developing and teaching tutorials.

Sustainability and dissemination

After all this work, how can you ensure that the materials are used in future iterations of the course? Furthermore, how can you make the products of your time and effort available to the community at large? Chasteen et al. (2010) have provided more details of the sustainability of our efforts.

Archiving of materials

For others to use your materials, they have to be able to access them in some sort of archive. Faculty have indicated they prefer these materials arranged so they can pick and choose what they want to use, rather than organized as a coherent curriculum. We have done this by providing a zipped folder of all course materials on the web as well as creation of a course materials management system (*www.sei.ubc.ca/materials/Welcome.do*). These provide models for course material organization in similar efforts. An STF or other support person is extremely helpful at this stage. Dissemination, however, is only one dimension of change strategy (Henderson, Finkelstein, and Beach 2010).

Departmental vision

There is a wide body of literature on the challenges surrounding change management and sustainable educational innovations (Henderson 2005; Henderson, Beach, and Famanio

2009; Henderson, Finkelstein, and Beach 2010; Moss-Kanter 1983; Rogers 2003; Tobias 1992). One theme in these writings is that lasting change is not created by lone visionaries; it is not possible to work alone and then "foist the innovation on the system from without" (Tobias 1992). Get key people involved early and "presell" the idea to them; plan how future instructors will be introduced to the goals, materials, and expectations of the course. Lasting change is created by committed departments working together to create programs suited to the local needs and academic culture—the innovation may have to be modified to fit with departmental politics, at the expense of the original ideal vision. This takes time and patience.

Team teaching

Team teaching of the transformed course helped support faculty in creating teaching innovations, improved the quality of the materials, transferred pedagogical skills, and broadened faculty investment in the new course. Team teaching has been shown before to be an effective method of promoting pedagogical change (Henderson, Beach, and Famanio 2009). The ideal coteacher is an instructor who is open to using new ways of teaching but is not yet sold on the idea.

Future instructors

We were able to arrange for the course to be taught for the next few years by faculty likely to continue the transformations. In this way, we hope that the transformations will become part of the departmental culture and context, and eventually faculty would have to justify why they chose not to use the transformed materials, rather than have traditional teaching be the status quo.

Overall, the materials that are "out of the box" (like tutorials and clicker questions) are more easily utilized, but the efficacy of these materials depends on whether and how the original pedagogical strategy (i.e., peer instruction) is being followed (Turpen and Finkelstein 2007; Turpen and Finkelstein 2009).

One concern that arises with course transformations is how much the success of the transformation depends on the instructor ("instructor effects"). This was a concern in E&M I, as the instructor of the first transformed course was an award-winning and enthusiastic lecturer. Could other instructors achieve the same results? Elby (2001) argued that the key to success is not the curriculum or the instructor, but rather the instructor's commitment to helping students learn how to learn, as supported by the curriculum but also by an overall attitude on the part of the instructor. Elby continues, "If this is correct, then other instructors can achieve the same results, even though teasing apart instructor effects from curriculum effects becomes less meaningful" (p. S62).

In this way, it becomes clear that the materials serve as support for a new teaching approach—the materials themselves do not comprise a successful course transformation (Pollock and Finkelstein 2008; Fullan and Pomfret 1977).

Conclusion

Course redesign is a process that can have profound effects on the education of thousands of students. We want to use the same scholarly approach in our approach to teaching as we do in our scientific research. We hope that this model of thoughtful course transformation assists other instructors who see the value in such an approach but who are not sure where to start. ■

Acknowledgments

We acknowledge the generous contributions of faculty at CU, including Drs. Beale, Betterton, DeAlwis, DeGrand, DeWolfe, Dubson, Finkelstein, Ford, Hasenfratz, Kinney, Munsat, Parker, Rogers, Schibli, and Zimmerman. This work is funded by the CU Science Education Initiative and NSF-CCLI Grant # 0737118.

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