A Thoughtful Approach to Instruction: Course transformation for the rest of us

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Abstract. We present a tested approach to transforming a course through incorporation of research-based methods and assessments. This approach can serve as a guide for faculty who wish to devote time and resources to improving a particular course to be more in line with principles of how people learn.

INTRODUCTION

As a community, we must ask ourselves “How successfully are we educating all students in science?” The data indicate that we are not where we want to be — too many undergraduates in our courses are not learning the science. We are fortunate, however, in that we have access to a growing body of research on effective ways to teach science. 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. 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) is to address this gap, to support and facilitate faculty in using research and assessment to guide the way we teach (Fig. 1). We have worked across 11 departments in 2 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.

FIG 1: The SEI Model of Course Transformation

THE TRANSFORMATION PROCESS

We have identified several important steps in successful course transformation (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. 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).
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<td>Facilitate meetings of faculty working group</td>
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<td>Course- and Topic-Level</td>
<td>What do we want students to learn (e.g., content, skills, habits-of-mind,</td>
<td>Facilitate meetings of faculty working group</td>
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<td>Learning Goals</td>
<td>attitudes)?</td>
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<td>How do students think about the material of the course, and what do they</td>
<td>• Do literature review</td>
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<td>Student</td>
<td>know coming in?</td>
<td>• Observe course before &amp; after transformation</td>
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<td>• Interview students</td>
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<tr>
<td>Teaching</td>
<td>How will we help them learn the material?</td>
<td>• Create course materials consistent with research on how people</td>
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<td>• Student interviews</td>
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<td>Materials</td>
<td>How will others find/use what we’ve done?</td>
<td>Organize materials locally and online</td>
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<td>Archived</td>
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<tr>
<td>Plan for</td>
<td>How will the fruits of our labors be adopted and/or adapted by others?</td>
<td>Interact with faculty and administrators prior to and following</td>
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<td>Sustainability</td>
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<td>transformation; Implement support strategies such as co-teaching</td>
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TABLE 1: Central features of course transformation

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 brownbag meetings, we began by discussing the course in general, such as where it fit into the departmental curriculum and what were the perceived opportunities for improvement. 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. We’ve found it useful to consider both course-level and topic-level learning goals. A course-level goal might be:

*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 towards 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.

**Why Learning Goals?** Learning goals effectively define what it means to “understand” in the context of this course, and provides a vehicle for faculty to more effectively communicate to students and to other faculty what students are expected 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’s 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), and be clearly related to what students would see as valuable things to learn. Several resources exist to assist in articulating learning goals.

For E&M I, a working group of about 10 faculty – most of whom had taught the course previously – met 6 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 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 importantly, how faculty members interact with their students. Nevertheless, it is seldom

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* All learning goals, assessments, and other materials for this course are available at [http://colorado.edu/sei](http://colorado.edu/sei)
a trivial task for a group of faculty to arrive at a consensus on learning goals for a course.

FIG 2. Students discuss a concept question

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, 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 course. This is not a bad thing in itself, but it’s not likely to solve all the problems in the course because faculty seldom know what all those problems are. 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 in office hours
- Reading through homework and exams and documenting common errors and difficulties
- Administering and evaluating a short (content) survey or 2-minute paper(s) in class
- Interviewing students

In E&M I, we observed a traditionally taught class, ran group sessions to help students on 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.

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.

Where to Start? There are many models of how to create course materials. 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 or by other faculty members. Familiarity with research-based pedagogical approaches, 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. 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.

<table>
<thead>
<tr>
<th>Course Element</th>
<th>Details</th>
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<tr>
<td>Interactive Lecture</td>
<td>“Mini” lectures interspersed with: clicker questions with peer discussions (Fig. 2), whole class conversation, simulations, student work on small whiteboards, short writing assignments, and kinesthetic activities.</td>
</tr>
<tr>
<td>Additional organized activities</td>
<td>Weekly tutorials (Fig. 3) reinforced and expanded on topics in lecture and prepared students for homework. Weekly homework help sessions. Optional but well-attended.</td>
</tr>
<tr>
<td>Homework</td>
<td>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.</td>
</tr>
<tr>
<td>Assessments</td>
<td>Traditional exams, Research-based conceptual post-test (e.g., CUE), Student feedback on informal surveys, Student attitudes as measured by the Colorado Learning Attitudes about Science Survey.</td>
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**TABLE 2: Course elements in E&M I.**
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, though challenging to convey to new instructors.

Assessment should be given high priority; it is a powerful tool for convincing your colleagues (and yourself) whether 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.

Assessments. Three typical electrostatics exam problems were given to students in two of the courses (“Trad” and “IE-1”) and 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. 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 traditional problems and the CUE assessment (Figure 4). Differences between Traditional and Transformed courses are statistically significant. Thus, by both measures, the course transformations were highly successful. As of writing, we are in the 4th semester of the transformed course, and are evaluating how materials are used by non-education-research faculty teaching successive semesters of the course.

DID IT WORK?

To determine whether the changes we made to the course were effective, we compared outcomes from a total of 9 courses at CU and elsewhere, including 4 semesters taught using the transformed course materials (3 of which were at CU).

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 courses (CU-IE1 through CU-IE3) were taught first by the curriculum developer (a member of the Physics Education Research [PER] group), then by another PER instructor with a non-PER co-teacher, 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 Transformed courses, as judged by end of term surveys. Attendance in lecture was higher, on average, for the 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 Transformed courses spent more time on task.

“HOW DO I DO ALL THIS?” MODELS OF TRANSFORMATION

It can be difficult to incorporate an extensive effort at course improvement 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:

- 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 TA’s)
- Hire a facilitator or support person, such as a science teaching fellow (STF) -- a temporary post-doc 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\textsuperscript{36}, 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 visit our website\textsuperscript{37} 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 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’s being taught prior to the transformations, and listening to students. These practices are then combined with instructor reflections on their own teaching practice, and information from the research literature.

Lastly, good undergraduates can provide a surprising amount of assistance in course transformation. We made use of two undergraduates\textsuperscript{38, 39, 40} in our transformations, who assisted with writing clicker questions based on their experiences in the class, and 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?

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\textsuperscript{41} as well as creation of a course materials management system\textsuperscript{42}. 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\textsuperscript{43}.

Departmental Vision. There is a wide body of literature on the challenges surrounding change management and sustainable educational innovations\textsuperscript{28, 28, 43, 44, 45, 46}. One theme in these writings is that lasting change is not created by lone visionaries; it’s not possible to work alone and then “foist the innovation on the system from without.”\textsuperscript{28} Get key people involved early and “pre-sell” the idea to them, and 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\textsuperscript{47}. The ideal co-teacher 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; Fig. 5) is being followed\textsuperscript{48, 49}. One concern that arises with course transformations is how much the success of the transformation depends upon the instructor (“instructor effects”). This was a concern in E&M I, as the Transformed instructor was an award-winning and enthusiastic lecturer. Could other instructors achieve the same results? Elby\textsuperscript{50} argues 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 an overall attitude on the part of the instructor. Elby continues,

\textit{If this is correct, then other instructors can achieve the same results, even though teasing apart instructor effects from curriculum effects becomes less meaningful.}

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\textsuperscript{51, 52}. 
CONCLUSIONS

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 to 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

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FIGURE CAPTIONS

FIG 1: The SEI Model of Course Transformation

FIG 2: Students discuss a concept test in E&M I.

FIG 3: Students in Tutorials in E&M I

FIG 4: Assessments in Traditional vs. Transformed courses at XX (name of institution) and elsewhere (N=220). Traditionally taught courses include CU-TRAD (N=41) at our institution and Non-CU-TRAD (N=73) – the average of two courses at another public institution. Transformed courses at our institution include XX-IE1 through CU-IE3 (N=20, 47, 27) at our institution and Non-CU-IE represents a small liberal arts college using our transformed curriculum (N=12). The CUE (name of diagnostic) consists of those questions given in common between courses, as the instrument changed over time. Error bars are +/- 1 standard error of the mean.
REFERENCES

9 On the web at http://colorado.edu/sei
10 XXX.htm
11 For more documents on course transformation, see www.cwsei.ubc.ca/resources/other.htm#transform
16 See, for example, http://www.cwsei.ubc.ca/resources/learn_goals.htm or https://www.fdi.vt.edu/summer/2004/content/trackg/unit2/default.html
18 All collection of student data for research purposes was subject to Institutional Review Board (IRB) approval – an important consideration in gathering data for research purposes. Students in the current study completed consent forms for participating in aspects of the research not considered part of normal class operations (i.e., student interviews, but not homework or exam completion).
27 Inspired by work by others, such as references 20-23.
26 One CUE question was adapted from C. Singh (personal communication); several clicker questions adapted from B. Hinrichs (personal communication) and Singh., C. 2006. Student understanding of symmetry and Gauss’ law of electricity. Am. J. Phys. 74 (10): 923-926.
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32 A set of useful faculty guides available at http://testing.byu.edu/info/handbooks.php
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