

2011-2012 Annual Report
for the
CU Science Education Initiative

Covering periods January 2011 – July 2012

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2011-2012 Executive Summary of CU's Science Education Initiative

The goal of CU's Science Education Initiative (SEI) is to improve undergraduate education in the sciences. For each course, this process involves a three-part process:

- 1) establishing well-defined learning goals through faculty consensus,
- 2) creating valid assessment tools for measuring attainment of these learning goals,
- 3) creating and using pedagogically effective materials and teaching approaches that are:
 - aligned with the learning goals,
 - based on and aligned with established research on how people learn,
 - based on research into student thinking about and learning of the content, and
 - improved through research (assessment and iteration).

Achieving this goal requires substantial changes to the standard university departmental and faculty culture surrounding undergraduate education. The funding provided to departments through the SEI has enabled the hiring of 2 or 3 Science Teaching Fellows (STFs) within each department. The STFs facilitate, guide, and support faculty as they learn about research on learning and engage in transforming their own and the departments approach to teaching. The STFs also investigate student thinking and measure student learning, and by doing so, provide faculty with the data they need to make informed choices about teaching approaches.

After 6 years, a significant number of faculty in 7 departments (APS, CHEM, EBIO, GEOL, IPHY, MCDB, PHYS) have been impacted by the SEI, modifying their teaching, creating and using learning goals, and using information on student thinking to guide their teaching. Faculty are engaging in research-based teaching methods and educational issues. The SEI project has also impacted a large number of courses, through in-depth interaction with faculty teaching those courses, developing learning goals in collaboration with faculty, and developing and administering validated assessments of student learning. These changes have impacted over 10,000 students per year, considering courses in which STFs have been both fully and partially involved. The SEI has also impacted departmental culture, affecting the frequency of discussions about teaching and learning in departments, and leading to numerous grants to continue the work begun by the project.

In summary, faculty, current and future students, individual departments, and the university as a whole are substantially benefitting from the investment CU has made in the SEI project. The learning environments and structures are overall more effective; the faculty have defined their learning goals and the curricular materials focuses on achieving those goals; the faculty are better educated in research on teaching and learning, particularly as they apply to the specific content of their courses and how students think about that content; and the faculty engage in and value research on their own student's learning – e.g. through the use of formative assessment tools such as clickers to probe and immediately respond to their students' thinking.

See later reports for more detailed numerical impacts of the SEI.

I. Overview of the Science Education Initiative

The CU Science Education Initiative is designed to implement and coordinate departmental-wide improvement of undergraduate science education. The major goal of the SEI is to bring about the sustainable transformation of the teaching of science on a department-wide basis to employ the research-based methods that have been shown to be highly effective in achieving faculty-defined learning goals.

While it is essential to improve science education at major research universities, the task is formidable. These science departments are large entities with established practices and are subject to a variety of economic and external constraints, providing barriers to change. The approach of the SEI is two-fold: 1) to have the faculty and the department initiate their involvement in and commit to participation in the SEI, and 2) to lower the time and money challenges by providing the funding needed to carry out these department-initiated activities.

The SEI efforts in each department are focusing on sequentially targeting courses for improvement, often beginning with the large introductory courses. Working in conjunction with the participating department, the major elements of the SEI-department efforts for each targeted course include:

- 1) establishing well defined learning goals,
- 2) creating valid tools for diagnostic assessment of attainment of learning goals,
- 3) identifying student thinking,
- 4) creating and using pedagogically effective materials and teaching approaches, and
- 5) developing faculty knowledge and practices.

Below, we provide details on the central SEI activities that are being conducted in support of the project, followed by a summary of the SEI budget. In the last five sections, the participating departments (Chemistry, Geological Sciences, Integrative Physiology, MCDB, and Physics) summarize the structure of the SEI project within their department, the course-related activities in 2011-12, faculty involvement in the SEI, and departmental goals for 2013.

II. Central SEI Activities

A. Update on central staffing

In September, 2010 Carl Wieman was selected to serve as the Associate Director for Science at the White House Office Science and Technology Policy, and was required to relinquish his position as director. Up until that time, Dr. Wieman actively directed the CU Science Education Initiative, traveling to Boulder several days each month. Currently, associate director, Kathy Perkins is acting director for the program. Dr. Perkins continues to establish collaborations between the CU and UBC SEI efforts where beneficial, along with the acting director of the UBC SEI, Dr. Sarah Gilbert.

Dr. Stephanie Chasteen continues to serve as the outreach coordinator for the project, creating videos about effective teaching, conducting faculty workshops, maintaining the website, and serving as a resource for the STFs.

The SEI Central project coordinator has been replaced. Marjorie Merges (Frankel) has left the program, and Oliver Nix spends a portion of his time assisting with administrative tasks for the SEI.

B. Funding departmental-based efforts

Several departments have completed their SEI programs. In 2011, CHEM, GEOL, IPHY completed their programs. MCDB and PHYS have continued their SEI programs, with new hires in each department (2 in physics, 1 in MCDB). Additionally, two departments have begun new SEI programs: APS and EBIO, with one new hire in APS and two in EBIO. Thus, since January 2011, 6 new hires have been added across departments.

A summary of the activities in each department is provided in the last sections of this report.

C. Activities to support departmental-based efforts

The SEI central staff (Kathy Perkins, Stephanie Chasteen, and Oliver Nix) support the departmental-based efforts in a variety of ways:

1. Perkins and Chasteen serve as resources to all of the STFs: advising them on the results of learning research, techniques of education research, and new effective teaching practices; reviewing their activities and progress and providing guidance and advice where needed; and providing them with appropriate professional development opportunities.
2. Perkins and Chasteen meet semi-regularly with each department's central SEI team (nominally the STFs and the faculty liaison) to review the department's progress on their efforts and their plan for future work. They provide guidance and advice where appropriate. In addition, they provide central support for certain activities where appropriate (e.g. resource materials for workshops or for administering surveys).
3. To foster communication between departments, Perkins and Chasteen hold monthly meetings with all the STFs – promoting STFs sharing with and getting feedback from the other STFs.
4. In May 2011, Perkins hosted the sixth end-of-term SEI sharing session – a half day even in which each of the 5 participating departments presented some highlights of their activities over the course of the term with time for discussion among the faculty. This event was held in coordinate with the Integrating STEM (iSTEM) initiative on campus and served as a connection-point for diverse stakeholders in science education across campus.
5. Chasteen provides pedagogical support materials (videos, booklets) to STFs for use as they work with faculty on teaching innovations.
6. Chasteen and Nix provide periodic updates to the website on SEI and STF activities.

D. Resources for faculty

The central SEI staff currently provides and is creating additional central resources for faculty working on improving science education on campus.

1. Invited Speakers

The central SEI encourages and supports each department in inviting noted education researchers and reformers in their disciplines to participate in their colloquium series. We believe this is the best way to expose additional faculty to this discipline-based education research that is being conducted and is valuable to their efforts as teachers.

2. Workshops/Brownbags

Faculty working groups have continued in several of the participating departments. These working groups have been established to tackle various goals within each department.

3. Teacher guides

In collaboration with the UBC SEI project, we have created a series of teacher guides covering some of the key pedagogical findings from education research and some practical advice on various pedagogically effective teaching practices. These include:

- “Assessments that support student learning.” Two page summary on Implementing good assessment.
- “Basic instructor habits to keep students engaged.” Two pager with tips on keeping students engaged in the classroom, especially large lecture halls.
- “Course alignment.” Two page review of aligning course goals and instruction.
- “Considering the student perspective: Factors that undergraduates perceive as influential to their academic careers.” Two page summary of research on undergraduate attitudes, with recommendations for faculty.
- “Teaching expert thinking.” A guide for using invention activities to develop expert thinking.
- “Thought questions: A new approach to using clickers.” A two page summary on an innovative use of clickers.
- “Clicker Resource Guide: An instructor's guide to the effective use of personal response systems ("clickers") in teaching.” University of Colorado SEI and University of British Columbia CWSEI staff & associates.
- “First Day of Class: Recommendations for Instructors on establishing the course environment early in the Term.” University of Colorado SEI and University of British Columbia CWSEI staff & associates.
- “Group Work in Educational Settings: A short description of different approaches to student group work and their benefits, requirements, and implementation logistics.” University of Colorado SEI and University of British Columbia CWSEI staff & associates.
- “Learning Goals/Objectives Examples: Good examples of learning goals: developed by departments involved in the Science Education Initiatives at UBC and the University of Colorado.” University of Colorado SEI and University of British Columbia CWSEI staff & associates.
- “What All Instructors Should Know.” University of British Columbia CWSEI.

4. Short Videos

The CU and UBC projects have co-invested in the creation of a series of short videos highlighting various pedagogically-effective teaching practices. These videos

achieve some of what written text cannot provide – a look at actual classroom implementation, showing what these techniques look like in practice. All videos also include both instructor and student comments, so that instructors may hear opinions and best-practices both from their peers, and from the students engaged in these learning environments. Video also has the potential to appeal to a viewers' emotion, by showing the power of many of these instructional techniques, and through production elements such as music. These videos have been an important outreach mechanism for SEI faculty interested in explaining their teaching approaches.

To house these videos, we have developed a Clicker Resource Website, maintained at UBC SEI, at <http://STEMclickers.colorado.edu>, which includes links to the Instructor's Guide, clicker question banks using questions aligned with research on best-practices, articles and research literature on clicker use, and the videos.

To date, the videos produced include:

Group Work in the College Classroom

Clickers: Teachers and Students Speak

How to Use Clickers Effectively

Anatomy of a Clicker Question

The Research: Do Clickers Help Students Learn?

Explain to Your Students Why You're Using Clickers

Upper Division Clickers in Action

What Kinds of Questions Do We Ask in Upper Division?

Writing Upper Division Clicker Questions

The "Clicker Resource Guide", as well as the pedagogical videos on clickers and group work, have received national attention and can also be found on i>clicker's website.

5. Website

The SEI website provides general information about CU's SEI project and serves as a source for faculty to access information about various education research findings (both general and discipline-specific), handouts and PowerPoint slides from SEI workshops, and course-related resources. The UBC SEI has a more extensive collection of faculty resources which we plan to mirror on the CU SEI site. The website can be found at: <http://www.colorado.edu/sei/>.

In addition, the CU SEI effort collaborated with the UBC SEI effort to build a much more sophisticated database of resources for faculty that allows faculty to upload their own resources or to search existing resources. This software has been piloted by CU and UBC STF's and faculty, and is available at <http://www.sei.ubc.ca/materials/Welcome.do>

III. SEI in Astrophysical and Planetary Sciences

The SEI program in Astrophysical and Planetary Sciences began in September 2011.

A. Departmental structure of the SEI program

Steve Iona was the STF from fall 2011 through spring 2012. The work of the STF was advised by Drs. Seth Hornstein, Doug Duncan and Jack Burns.

The APS department has 4 introductory courses: ASTR1000, ASTR1200, and ASTR1010 and ASTR 1020. ASTR1000 and ASTR1010 teach the solar system, the other two teach stars, galaxies, and cosmology. ASTR1010 and 1020 form a sequence. 1010 has a 2 ½ hour weekly lab, taught by graduate student TAs and several learning assistants (LAs). 1020 was modified to have one hour LA-led recitations after the LA program began approximately 10 years ago. ASTR 1000 and 1200 do not have any small group meetings.

ASTR1010 has had a lab book for decades, with the labs slowly being improved, especially as the department became involved in science teaching research. ASTR1020 had no book of activities for LAs to do in recitation. Historically, each faculty member teaching 1020 simply made up activities for LAs to do. A main goal of the SEI program in APS was to create better materials for the 1020 recitations.

B. Course-related efforts

APS faculty members were asked for input for prioritizing tasks for the STF. Specific choices mentioned included: develop a bank of field-tested clicker questions, codify useful lecture demonstrations used by the faculty and staff, give one-on-one feedback to faculty members about their teaching, improve/develop more rigorous night-observing activities for ASTR1010/1020, improve/develop labs (particularly: optics, seasons, and collisions) for ASTR1010, improve/develop more formalized recitation activities for ASTR1020.

A majority of faculty members prioritized developing activities for ASTR1020 LA-led recitations as the top priority, and that is what Steve Iona worked on. Iona's first step was to determine Learning Goals and specific Learning Objectives for this course. This proved difficult because only a few faculty members were willing to offer these. Iona resourcefully asked for the Power Points of faculty members who have taught ASTR1020 recently and he developed Learning Goals and Objectives from these. The high-level learning goals are attached as Appendix 1. The specific Learning Objectives of each faculty member who teaches 1020 were collected in an Excel spreadsheet and in the new handbook (see next section).

ASTR 1020

A number of recitation activities for LAs to lead were taken from the book, "Lecture Tutorials for Introductory Astronomy," by Prather et al. Open copyright access was

obtained because of the long-standing relationship among CU-APS professors Duncan and Hornstein and Edward Prather and his working group. Also, APS Ph.D. student Colin Wallace developed some of the tutorials on cosmology and went from CU to Arizona as Prather's postdoc. PDF and DOC files for the Tutorials are now available to APS faculty. In some cases, the Tutorials were altered to better match the content or pedagogy used in ASTR1020. Other recitations were developed using work from CU-APS faculty, and some other Recitations were developed by Iona to fill a need within the class for content. Most of the recitation activities were tested once with students.

The newly-developed ASTR1020 Recitation Handbook was printed and made available to faculty who teach the course.

IV. SEI in Chemistry

The SEI program in Chemistry ended in May 2011.

V. SEI in Ecology and Evolutionary Biology

A. Course Support Activities

1. General Biology (EBIO 1210 and 1220)

Sarah supports the General Biology course sequence (EBIO 1210 and 1220). This large enrollment, 4-section course features a rotating cast of faculty instructors each quarter. Two tenured and six tenure-track faculty are involved, as well as a lab coordinator/instructor and a course coordinator.

Only the two tenure-track faculty (Barbara Demmig-Adams and William Adams) declined Sarah's "typical" support (below). This is because prior to the SEI grant they engaged in their own intensive process of developing learning goals, challenging clicker questions and homework, and aligning these to exams.

Sarah's typical support:

- Initial meeting(s) to discuss faculty goals for course transformation
- suggestions in advance of lecture for: revising clicker questions to be more conceptual, challenging, and frequent; reducing content and terminology; altering slide order to better stimulate student thinking/prediction; audiovisual enhancements; all embedded into the lecture .ppts that are going to be revised
- extensive quantitative and qualitative feedback on every lecture, including an impression of the learning goals encapsulated by the lecture (for future use).
- verbal feedback after every lecture or through a weekly meeting, focusing particularly on implementation of clicker questions and stimulation of student discussion
- connections to research/resources as applicable
- Bloom analysis of exam items and suggestions for revision

- Followup meeting to discuss transformation experience and future plans
- Detailed, data-based teaching observation letter for the faculty's tenure/merit file

In the second half of the fall of 2011, Sarah supported Sam Flaxman, who was teaching all 4 sections. In addition to the typical support, they together:

- implemented a pre-post assessment (using questions from the validated GCA and BCI inventories)
- revised and incorporated a case study on chromosomes, sex-determining genes and gender from the SUNY Buffalo case study archive
- incorporated "roadmap" and summary slides for better student orientation to the big ideas in lecture

In cases where feedback would substantially improve active learning or provided an opportunity for a "natural experiment" useful to Sam, Sarah made verbal suggestions in between Sam's back-to-back lecture periods. Sam indicated he valued both types of feedback and very quickly incorporated suggestions related to implementation of clicker questions. Sam continues to be active in the SEI.

In the first half of spring 2012, Sarah supported Becca Safran, who was teaching 2 sections. She didn't directly support the instructor of the other 2 sections (Piet Johnson, who was a new father) but Becca shared materials and ideas that Sarah produced with him. In addition to the typical support, they together:

- Identification of new focal learning goals for the first ½ of this segment (4 weeks): the interpretation and construction of phylogenies, the testing of evolutionary hypotheses, and the selective advantage of 10 animal evolutionary innovations and their phylogenetic appearance.
- "overhaul" of these first 4 weeks of lecture, including an expansion of the evolution content, a massive reduction in the "march of the phyla" biodiversity content, and large rearrangements/deletions/insertions of slides and clicker questions.
- development of re-useable phylogeny graphics to run throughout the overhauled series of lectures
- revised and incorporated a case study on whale evolution, with help from Anne-Marie

In followup meetings with Becca, she indicated that the overhaul and feedback was extremely valuable to her, but was also a bit overwhelming, and feedback involving critical comments from students were disheartening. Sarah did damage control around these experiences and tweaked her approach to working with Becca the following year. Becca continues to be involved and positive about the SEI and positive about it.

In the second half of the spring 2012 semester, Sarah worked with Brett Melbourne and Kendi Davies. They are married and co-create all their curricula and exams. Kendi taught all 4 sections this particular spring so most of Sarah's contact after the initial planning was with her. In addition to the typical support, they together:

- implemented a pre-post assessment (using questions from the validated GCA and BCI inventories)
- “overhauled” weeks 2-4 of lecture (~1/3 of their lectures) to emphasize the similarities between and evolutionary patterns among plant life cycles. This overhaul involved an expansion of the evolution content and a massive reduction in the “march of the phyla” biodiversity content.
- development of re-useable life cycle and phylogeny graphics to run throughout the overhauled series of lectures; incorporation of some of these graphics into small in-class exercise handouts
- incorporated a new case study on fungal disease causing global frog population declines, with help from Anne-Marie
- carried out an educational experiment to test the effect of formal group declaration on student clicker performance and discussion (see Research section)

In followup meetings Kendi indicated that she enjoyed teaching her transformed course much more than before. She was very enthusiastic about her experiences and indicated an intention with Brett to completely “flip” their course (nearly all active learning). However, some of her and Becca’s FCQs from this quarter were lower than before and certain tenured faculty pressured them to reduce their ambitions for further transformation fearing impacts to their impending tenure process (more on that in upcoming annual reports). Kendi later did an analysis which showed that her FCQs were lowest in sections which received her “group” treatment and which were previously taught by Piet Johnson (who used less active learning than Becca). Therefore, the FCQ effect was likely related to how “different” the learning experience was perceived by the students in each section, leading to a greater focus on buy-in for the following year. Kendi and Brett remain positive and involved in the SEI.

During the spring of 2013, Sarah met weekly with John Basey to characterize and revise the learning goals in the General Biology I and II lab manuals. Additional revision suggestions to lab wording and assessment were also made. Revisions were incorporated into the 2013 student lab manuals and John Basey indicated that both the process of discussing the learning goals and the final revision were very valuable in clarifying the largely process-oriented learning goals for students and for his Gen Bio I and II faculty collaborators.

2. Ecology-track courses

Anne-Marie’s course support activities centered around the department’s ecology-track courses. Currently, two faculty members teach the department’s lower-division general ecology course, and entrance point for all EBIO majors. Anne-Marie visited approximately half of Bill Bowman’s class periods in fall semester 2011. During the semester, Anne-Marie worked with Bill to write (model) clicker questions and, eventually, provided feedback for Bill when he began to write his own questions. This classroom observation time also allowed Anne-Marie to work with ecology faculty, including Kendi Davies, Brett Melbourne, Bill Bowman, and evolutionary-ecology faculty and PI Andy Martin when this small working group began assembling the department’s first set of comprehensive learning goals for the ecology portion of the EBIO major.

In the second half of fall 2011, Anne-Marie worked with Sam Flaxman to choose and modify a case study he used when teaching his general biology course. Sam showed Anne-Marie his learning objectives, and Anne-Marie chose from among several existing case studies, which Sam and Anne-Marie then modified to align more closely with Sam's objectives. Sam then ran the case study in his general-biology classrooms with Sarah and Anne-Marie observing and providing feedback.

In spring 2012, AMH worked with RS to deploy her overhauled lectures. AMH also assisted RS to identify and use a case study on speciation in her lecture sections. In the second half of spring semester, AMH wrote a case study based on existing course material for KD in support of their section on fungi. In general biology, we tested the discriminatory value of some potential pre-/post-test concept inventory questions focused on population ecology, trophic interactions, and plant and fungus diversity and life cycles.

B. Departmental Support Activities

Sarah organized a listening tour of all interested faculty during August and September of 2011; Anne-Marie and Sarah met with a total of 10 faculty during that tour and used what we heard to plan out our approach for the following year. At least 3 additional faculty were met with as their schedules allowed

Anne-Marie and Sarah traded off on leading a weekly SEI department workshop during the Fall 2011 and Spring 2012 semesters. Topics of these meetings included:

- defining common interests/goals of EBIO SEI faculty
- the Teaching Perspectives Inventory
- writing learning goals
- using learning goals to inform course content reduction
- getting started with clickers (technical aspects)
- clicker question form and function
- clicker data analysis
- writing/implementing case studies
- science process skills/ the Vision and Change report
- factors influencing student motivation
- integrating curricula across the major
- purposes and options for formative/summative assessment

Faculty were offered preparatory work and readings for some of these workshops; for example, readings on student motivation were selected from "How Learning Works". Topics of meetings were arrived at collaboratively; in spring 2012 we used a ranked survey of all SEI-interested faculty to plan meeting topics. In spring 2012, full-group meetings were held on alternating weeks with small-group meetings devoted to working on learning goals for Ecology (with Anne-Marie) and Genetics (with Sarah).

Anne-Marie established an EBIO SEI email listserv and Dropbox folder that is open to anyone on the faculty. The email listserv is used to share EBIO SEI meeting minutes, online teaching resources, on-campus seminar announcements and other resources, relevant news items, and timely research papers.

Anne-Marie and Sarah updated the entire department on SEI activities on Oct 13 and Dec 8, 2011, at departmental faculty meetings.

AMH worked with a sub-group of ecology faculty (Nichole Barger, Bill Bowman, Kendi Davies, Brett Melbourne, and Andy Martin) to develop comprehensive ecology learning goals. Alex Cruz, one of two faculty who regularly teach the sophomore ecology course (an entrance point for all EBIO majors), largely declined to be involved in this process.

C. Research

SITAR. With Anne-Marie and Andy Martin, Sarah developed the SITAR observational tool (Student Interaction and Teaching Activity Report). Together they established inter-rater reliability for the “Teaching Activities” portion of this report. Sarah used quantitative data from this tool to describe faculty and student activities for faculty tenure files, and in the form of a poster for the SEI End-Of-Year Event. Sarah has continued to use this tool in providing daily feedback to faculty.

Group Sign-Up Experiment. Sarah and Anne-Marie assisted Kendi Davies and Brett Melbourne in experimentally testing the hypothesis that providing a small bonus incentive to students for signing up online with their clicker discussion group would lead to improved clicker performance, post-test performance, attitudes toward group discussion, and/or engagement in discussion (self reported and gestural data). There were three treatment and one control sections. Sarah arranged for online signups via a website Mike Dubson set up for the course, piloted the collection of decibel data (later scuttled) and gestural data, developed the survey tools, and managed the data collection and analysis (ongoing – to be completed spring/summer 2013). Initial gestural and FCQ data indicate a difference between treatment and control groups.

Ready to flip? AMH, NB, and AM worked on a manuscript over the summer months. Its thesis was providing recommendations to instructors thinking about or preparing to flip their classrooms. The article is in review in *Bulletin of the Ecological Society of America*.

Problem-solving in biology. AMH initiated a project with Danny Caballero (Physics STF) and Jenny Knight (Senior Instructor, MCDB) researching how PER could inform BER in developing students’ abilities to solve the complex problems that characterize biology. This project continued until January 2013, when the manuscript was accepted in *CBE-Life Science Education*.

VI. SEI in Geosciences

The SEI program in Geosciences ended in July 2011.

VII. SEI in Integrative Physiology

A. Department Structure

The SEI program in Integrative Physiology ended in September 2011. The following report covers the work of Dr. Teresa Foley in Summer 2012.

B. Course-Related Efforts

1. Physiology Labs

Teresa helped finalize the new inquiry-based format of the Physiology laboratories. This included:

- Finalizing 3-5 clear learning goals for each lab (10 labs total).
- Developing 3 new inquiry-based labs.
- Making final revisions to the lab manual based on feedback from the teaching faculty.
- Transforming the lengthy lab write-ups into 1-2 page worksheets that could be easily graded by the teaching assistants.
- Training the new Lab Coordinator, Molly Welsh, on the inquiry-based format.

In the future, Teresa will work with the Physiology Lab teaching faculty to:

- Update and “bloom” the assessment tools (10 quizzes, 3 lab exams).
- Incorporate statistical tests and graphing techniques to the lab manual.
- Finalize and validate a pre-post assessment that gauges student learning.

2. Human Physiology I

Based on feedback from the faculty, the Department asked Teresa to reexamine the learning goals for IPHY 3470 (Human Physiology I). The goal of this revision was to eliminate any redundant/extraneous goals and to align the goals with the other IPHY core courses and laboratories.

The revised goals have been sent to Stephanie for placement on the SEI website.

3. IPHY TA Training

Teresa helped Ruth Heisler direct a 4-hour workshop for the incoming graduate teaching assistants (n=30). Topics covered in this training included:

- Active vs. passive learning
- Novice vs. expert thinking
- Professionalism
- Building a teachable unit

The materials for the IPHY TA Training have been sent to Stephanie for placement on the SEI website.

VIII. SEI in MCDB

A. Departmental structure of the SEI program

| <u>Current staff</u> | <u>Position</u> |
|----------------------|---|
| Dr. Jennifer Knight | Coordinator |
| Dr. Bill Wood | Director |
| Dr. Brian Couch | Science Teaching Fellow (full-time, Jan 2012-present) |

| <u>Previous STFs</u> | <u>Current Position</u> |
|----------------------|---|
| Dr. Sarah Wise | STF in Ecology & Evolutionary Biology (EBio) |
| Jia Shi | Academic Advisor in Integrative Physiology (IPhy) |
| Dr. Michelle Smith | Assistant Professor (UMaine) |

Dr.

B. Course-related efforts

1. General

Previous SEI-facilitated efforts have resulted in the core MCDB courses, as well as some additional electives having:

- 1) Course- and topic-level learning goals. The learning goals for each core course are shared with the students (usually via the course website) and frame the teaching of each course.
- 2) Interactive learning approaches, including in-class concept questions (clickers), small group activities, co-seminars designed to give students a small group environment to practice solving problems, homework activities, and formative assessments.
- 3) Two published concept inventories: the Genetics Concept Assessment (GCA) (Smith et al. 2008) and the Intro Molecular and Cell Biology Concept Assessment (IMCA) (Shi et al. 2010).

We continue to publish our findings in peer-reviewed journals. A complete list of publications since the onset of the SEI is at the end of the report.

2. Courses previously modified

As mentioned above, the SEI has worked with the MCDB faculty to implement research-based teaching approaches across the curriculum. Below is a list of courses and faculty that the MCDB has partnered with in past years. Please refer to previous reports for course modification details.

- a) MCDB 1041 Fundamentals of Human Genetics (Jenny Knight)
- b) MCDB 1150 Intro to Cell & Molecular Biology (Nancy Guild and Jennifer Martin).
- c) MCDB 1152 Intro Co-seminar (Nancy Guild and Jennifer Martin)
- d) MCDB 2150 Principles of Genetics (Ken Krauter, Tin Tin Su; Mark Winey)
- e) MCDB 2152 Genetics Co-seminar (Nancy Guild, Christy Fillman)
- f) MCDB 3140 Cell Biology Laboratory Course (Joy Power)
- g) MCDB 3135 Molecular Cell Biology 1 (Cell Biology) (Greg Odorizzi, Gia Voeltz, Jingshi Shen)
- h) MCDB 3150 Molecular Cell Biology II (Molecular Biology) (Greg Odorizzi, Mike Stowell, Ravinder Singh)
- i) MCDB 4330 Immunology (Corrie Detweiler)
- j) MCDB 4650 Developmental Biology (Jenny Knight)
- k) MCDB 4777 Molecular Neurobiology (Kevin Jones)
- l) MCDB 4790 Experimental Embryology (Tin Tin Su)

3. *Sustainability*

Over the past year, we have visited many of the above courses to determine the degree to which they have maintained the modifications implemented with the SEI. From these observations and informal discussions with faculty, we are pleased to report that most of the changes implemented under the SEI have been maintained and many have been improved.

Faculty continue to use and renovate the extensive learning goals written for courses in our core series. Most faculty routinely use in-class clicker questions and problem-solving exercises, and the IMCA and GCA concept inventories are administered each semester on a pre-post basis to their respective classes. Overall, undergraduate education has gained an increasingly prominent position within departmental dialogue, and we are optimistic that our future work will continue to expand and enhance this dialogue.

B. Development of a Capstone Assessment tool for MCDB majors

Previous discussions with MCDB faculty and the departmental Undergraduate Committee (UGCOM) led to an agreement that the best way to sustain and improve research-based teaching in our core courses would be to develop an assessment tool to monitor if our students are graduating with the knowledge and skills that the department values as essential. Administered each year to seniors and intended to measure students' ability to integrate and apply their knowledge, this "capstone" assessment would direct the attention of the faculty toward specific

areas of difficulty and help shape our curriculum and teaching. Coupled with instituting a process for periodic review and updating of core course learning goals, this should ensure that core courses are adequately addressing the overall learning goals of the program.

Work prior to hiring Brian Couch was spotty, but a draft of goals and a few questions were built by Jenny Knight in collaboration with some faculty in the department, Sarah Wise, and MCDB undergrad Caleb Trujillo. We have made significant progress in the last year, and in particular since Brian's arrival. We are planning to pilot the final version of the assessment towards the end of this semester: the assessment is aimed at probing higher-level cognitive understanding of central concepts in biology, and consists of 18 multiple true/false questions. The assessment was designed through the following steps:

Step 1: Identify major concepts in biology and draft a set of related learning goals. Our learning goals are the product of roughly 20 faculty interviews, extensive textbook review, and student group discussions. Our final learning goals are framed within the core competencies recommended by the Vision & Change in Biology national report.

Step 2: Collect student thinking related to learning goals. For each concept, we drafted an open-ended question to probe student thinking and conducted interviews with 7-12 students per question.

Step 3: Draft forced-response questions based on student thinking. We elected to use the multiple T/F question format because it provides a much richer portrait of student thinking than simple multiple choice. We proceeded with validation efforts for 18 of these questions.

Step 4: Iteratively revise questions based on student and faculty interviews. For each question, we have conducted think-aloud interviews with 6-19 students and collected feedback from 7 faculty. We are presently working to conduct more student and faculty interviews and to bring questions into their final versions.

Step 5: Determine validity of final version through student interviews and faculty feedback. Once we have arrived at the final versions of each question, we will conduct a final set of student interviews to measure how well our items capture student reasoning. We will also send a survey to diverse faculty asking them to evaluate the content and appropriateness of each item.

Step 6: Administer pilot test to a large number of students. In addition to MCDB, we are currently recruiting teachers from diverse institutions to pilot our assessment to seniors this fall. We have commitments from several faculty and hope to enroll several more institutions in the coming weeks.

Step 7: Administer second version of assessment to a large number of students and perform statistical analyses to determine evidence of validity and reliability. We have enlisted the help of a statistician at the University of Washington to help with various aspects our analyses.

C. Faculty Presentations/Synergistic activities.

2011

Jenny and Sarah Wise, with Erin Furtak from the School of Education applied for and received an NSF TUES I award: Investigating instructional influences on the productivity of clicker discussions. \$196,672 (July 2012-June 2014).

Jenny was an invited speaker at:

University of New Mexico Medical School, Department of Biochemistry Faculty Seminar: Using clickers to maximize and measure student learning in biology. March 2011

University of New Mexico Medical School Annual Education Retreat. Talk and two workshops. October 2011

Jenny was a workshop leader for the week-long FIRST IV NSF-funded regional workshop for post-doctoral fellows.

Jenny, Bill and Brian are members of the Society for Advancement of Biology Education Research (SABER), and Jenny submitted 4 abstracts for the 2011 meeting (two talks, 2 posters).

Jenny taught MCDB 5650-Teaching & Learning Seminar in spring 2012. There were 18 participants in the class, including undergraduates, graduate students, and postdocs from several different departments.

Jenny and Bill led the National Academies and HHMI Mountain West Summer Institute at CU-Boulder in late July

Bill is a senior editor of *CBE-Life Sci. Educ.*, having stepped down as editor-in-chief in fall 2010, and co-editor of the W.H. Freeman Scientific Teaching Books series, with titles including *Scientific Teaching* (2007), *Transformations: Approaches to College Science Teaching* (2009), *Discipline-Based Educational Research: a Scientists Guide* (2010), and *Assessment* (forthcoming 2011). He serves on the National Academies Board on Science Education, the NRC Committee on Status, Contributions, and Future Directions of Discipline-Based Educational Research, the HHMI Science Education Advisory Board and the IQ Biology Program Advisory Board of the CU Boulder BioFrontiers Institute. He contributed a description of the SEI to the recently released AAAS/NSF report *Vision and Change, a Call to Action*. He also gave invited seminars on transformation of undergraduate science teaching at Yale U., U. of Nebraska, and Iowa State U. and presented a paper at the conference on “Research in Biology Education: Where do we go from here” sponsored by the Michigan State U. Institute for Research on Mathematics and Science Education.

2012

Jenny, Bill and Brian lead a local Biology Education Research journal club. This journal club meets biweekly and includes faculty, postdocs, and students from MCDB and EBIO.

Jenny and Brian co-taught MCDB 5650-Teaching & Learning Seminar in spring 2012. There were 16 participants in the class, including undergraduates, graduate students, and postdocs from several different departments.

Jenny and Brian participated in an NSF-funded exploratory workshop to coordinate the development of an overarching set of biology assessments aimed at monitoring student progress throughout the major. Pending funding acquisition (TUES II proposal will be submitted in January), this set of assessments will be modeled after the MCDB capstone, but will extend across all years and feature questions from ecology, evolutionary biology, and physiology, in addition to molecular and cellular biology.

Jenny, Brian and Bill attended the SABER conference in July. Jenny gave a talk and Brian gave a poster. Jenny is also now the head of the abstract review committee for SABER.

Jenny and Bill led the National Academies and HHMI Mountain West Summer Institute on Undergraduate Biology Education at CU-Boulder in late July. Brian was a participant.

Jenny gave an invited talk at the Experimental Biology Conference in San Diego, a plenary and two workshops at the University of Washington Medical School Annual Education Retreat, a faculty seminar at University of Northern Colorado, a talk at the Introductory Biology Project Conference in Washington D.C, and was a guest speaker at the Southeast Regional Summer Institute on Undergraduate Biology Education at the University of Georgia. In addition, she led the FIRST IV regional postdoc workshop, as in previous years.

Bill helped design and lead a four-day teaching and learning workshop in Pune, India, for 50 college level biology teachers from many different parts of the country. He was also appointed to the Advanced Placement Biology Exam Development Committee of the College Board.

D. Goals for 2012/2013

1) Draft and pilot final version of MCDB capstone. Administer MDCB capstone at CU-Boulder and other institutions during Fall 2012 and Spring 2013 semesters. Analyze data and consolidate for publication on instrument development and validity.

2) Draft report of findings for MCDB faculty. Work to incorporate our findings into the ongoing faculty curriculum dialogue. Facilitate adoption of departmental structures addressing the particular deficits seen in our students.

E. Publications of SEI-related research by SEI team members

- Knight JK and Wood WB (2005). Teaching more by lecturing less. *Cell Biol. Educ.* 4, 298-310.
- Knight JK and Smith MK (2010). Different but equal? How non-majors and majors approach and learn genetics. *CBE Life Sci. Educ.* 9, 34-44.
- Knight JK (2010). Biology Concept Assessment Tools: Design and Use. *Microbiology Australia* 31(1), 5-8.
- Semsar K, Knight JK, Birol G, Smith MK (2011). The Colorado Learning Attitudes about Science Survey (CLASS) for use in Biology. *CBE Life Sci. Educ* 10, 268-278.
- Shi J, Martin JM, Guild NA, Vincens Q, Knight JK (2010). A Diagnostic Assessment for Introductory Molecular and Cell Biology. *CBE Life Sci. Educ.* 9, 453-461.
- Shi J, Power JM, Klymkowsky MW. Revealing Student Thinking about Experimental Design and the Roles of Control Experiments. *In press: IJ-SoTL*.
- Smith, MK, Wood, WB, Knight, JK (2008). The Genetics Concept Assessment: A new concept inventory for gauging student understanding of genetics. *CBE-Life Sci. Educ.* 7, 422-430.
- Smith MK, Wood WB, Adams WK, Wieman C, Knight JK, Guild NA., Su TT (2009). Why peer discussion improves student performance on in-class concept questions. *Science* 323, 122-124.
- Smith MK and Perkins KK (2010). “At the end of my course, students should be able to ...”: The benefits of creating and using effective learning goals. *Microbiology Australia* 31(1), 35-37.
- Smith MK, Trujillo C, Su TT (2011). The benefits of using clickers in small enrollment seminar-style biology courses. *CBE - Life Sci Educ.* 10, 14-17
- Smith MK, Wood WB, Krauter K, Knight JK (2011). Combining peer discussion with instructor explanation increases student learning from in-class concept questions. *CBE-Life Sci. Educ.* 10,55-63.
- Smith, MK and Knight, JK (2012). Using the Genetics Concept Assessment to Document Persistent Conceptual Difficulties in Undergraduate Genetics Courses. *Genetics* 191, 21–32.

Wood, W. B. (2008) Teaching concepts vs facts in developmental biology. *CBE-Life Sci. Educ.* 7: 10-11

Wood, WB (2009) Innovations in teaching undergraduate biology, and why we need them. *Ann. Rev. Cell & Devel. Biol.* 25, 93-112.

Wood, W. B. (2009) Education Forum: Revising the AP Biology curriculum. *Science* 325: 1627-1628.

Wood, W. B. (2011) The challenge of changing the way we teach. In: *Research in Biology Education: Where do we go from here?* Symposium Proceedings, Michigan State University Institute for Research in Mathematics and Science Education, Chicago, IL, pp. 39-51.
(<http://irmse.msu.edu/category/colloquiums>)

Wood, W. B. and Tanner, K. D. (2012) The role of the lecturer as tutor: doing what effective tutors do in a large lecture class. *CBE-Life Sci. Educ.* 11: 3-9.
(<http://www.lifescied.org/content/11/1/3.full>)

IX. SEI in Physics

A. Departmental structure of the SEI program

The Physics Department was funded by SEI in Spring 2007. The intent of the proposal is to try to extend physics education research-based teaching methods into upper division physics curriculum for majors. Three Science Teaching Fellows have been hired by the department to support this work. Dr. Stephanie Chasteen started Fall 2007 and has focused on Electricity and Magnetism 1 (PHYS3310), with additional work in outreach beginning in 2009 and continuing to the present (see section on Outreach). Dr. Steve Goldhaber started Summer 2008, and has focused on Quantum Mechanics 1 (PHYS 3220), completing his position in the SEI in Summer 2010. Dr. Rachel Pepper started in Summer 2009 and has been continuing Dr. Chasteen's work in PHYS3310 and began work in Mechanics and Mathematical Methods (PHYS2210) in 2010. Paul Beale served as Departmental Director of the SEI efforts until 2011, and the current Departmental Director is Steven Pollock. Three faculty working groups have formed focusing on the three upper-division courses that are the focus of the SEI (PHYS3310 – Electricity and Magnetism 1, PHYS 3220 – Quantum Mechanics 1, and PHYS2210 – Mechanics and Mathematical Methods). The feedback of these groups of faculty has provided crucial direction for the STFs.

B. Course-related efforts

1. Overview

A rotating instructor schedule for E&M I and Quantum I is intended to promote sustainability of course transformations by involving a variety of Physics Education Research (PER) faculty in developing the transformations, as well as engaging non-PER faculty in those transformations at a deep level. Co-teaching allows transfer of skills

between instructors, a collaborative environment conducive to creating new teaching ideas and materials, as well as a reduced time-load for each instructor. This increases the opportunities to develop and implement new materials. As such, the following instruction schedule was set:

- Spring 2008 E&M I – Steven Pollock (PER)
Quantum I – Michael Dubson (PER)
- Fall 2008 E&M I – Michael Dubson (PER) and Edward Kinney (non-PER)
Quantum I – Steven Pollock (PER) and Oliver DeWolfe (non-PER)
- Spring 2009 E&M I – Edward Kinney (non-PER)
Quantum I – Oliver DeWolfe (non-PER)
- Fall 2009 E&M I – Thomas Schibli (non-PER)
Quantum I – Andreas Becker (non-PER)
- Spring 2010 E&M I – Oliver DeWolfe (non-PER)
Quantum I – Murray Holland (non-PER)

The SEI's formal involvement in instructor selection ended in Spring 2009. After that time, the assistant chair of the department assigned the course under his own jurisdiction, but accepted input from the SEI as to which instructors would be most likely to sustain the current reforms.

2. *Electricity & Magnetism I (PHYS 3310)*

Electricity & Magnetism 1 (E&M I), PHYS 3310, is required for completion of the BA in Physics, Astrophysics and the BS in Engineering Physics – about 80% of the course is populated by these majors. The remaining students are comprised of mathematics majors (11%), other natural science majors (4%), and other miscellaneous and undeclared majors (7%). Typically, this course is taken by juniors and seniors, and the enrollment is 30-50 students. Several faculty have taught this course – in the past five years. Recent instructors have been Anna Hasenfratz (taught twice), John Bohn, Uriel Nauenberg, Mihaly Horanyi, Charles Rogers, and Scott Parker. In about half the cases, the same instructor teaches PHYS 3310 and the second semester course, PHYS 3320.

Activities in E&M I include:

- a. a. Changes in course instruction

The course run in Spring 2008 by Steven Pollock was transformed to incorporate many pedagogical approaches aligned with research on learning and informed by information on student thinking about E&M that was gathered through observations and interviews in Fall 2007. Interactive lecture techniques were used in class, including clicker questions, kinesthetic, and white-boarding activities. In addition, homeworks for the class were reformed to explicitly include and require students to make more connections to the real world, practice more physicists' "habits of mind" such as examining behavior at limits and doing estimations, and more explanation of reasoning. Outside of class, biweekly group problem solving sessions were organized to focus on homework. Weekly tutorial activities were developed in order to give students an opportunity to work on some of the underlying conceptual ideas in E&M in a group setting. An optional weekly session where students worked through these tutorial activities was added to the course. The

tutorial sessions have since been institutionalized as optional one-credit co-seminar courses which do not count towards the major.

This course has served as a model for the E&M course offered by Dubson/Kinney in Fall 2008, Kinney in Spring 2009, Schibli in Fall 2009, and deWolfe in Spring 2010. All instructors made heavy use of the clicker questions, tutorials, lecture notes, homework, and other activities developed for the course. In addition, the lists of student difficulties developed during the course of Spring 2008 has served as a guide for instructors at CU and elsewhere. The course was taught by Parker in Fall 2010, who referred to our course materials but did not implement the pedagogical techniques such as clickers or tutorials. The course is currently being taught by Horanyi in Spring 2011, who also referred to our course materials, and used clicker questions, student difficulties, and study sessions, but no tutorials. Horanyi taught the course again in Fall of 2011 and continued to use the materials above and offered the optional tutorials run by PER graduate student Bethany Wilcox. Andreas Becker taught the course in Spring 2012 and reported referring consistently to the available course materials and used clickers, tutorials, study sessions, and some of the modified homework.

b. Course Materials

In Fall and Summer of 2008 a set of course materials were developed and organized by Steven Pollock and Stephanie Chasteen. All materials were based on detailed student interviews (Fall 2007 through Fall 2008) as well as detailed observations of lecture and group work. All later instructors (Dubson, Kinney, Schibli) improved upon and/or annotated these materials, resulting in a robust and diverse set of materials. These materials include:

- COURSE CALENDAR, including activities and covered material
- HANDOUTS AND POSTERS, such as a detailed “crib sheet” for the course and posters of Maxwell’s Equations
- STUDENT DIFFICULTIES pertinent to each chapter of the textbook, as compiled by observations in student interviews, homework help sessions, written homework, and tutorials over the course of 2 semesters.
- LEARNING GOALS for the course overall, and for individual chapters, developed from meetings and interviews with the faculty working group
- CONCEPTTESTS** (a.k.a. ‘clicker questions’) for individual chapters. Several hundred questions have been developed in all, annotated with class responses and instructor observations.
- LECTURE NOTES**
- CLASS ACTIVITIES: Lists and descriptions of interactive activities for each topic area in the course, including lecture demos, kinesthetic activities, whiteboards, and group work.
- HOMEWORK ASSIGNMENTS** and solutions, and detailed observations of student performance for assessment of the value of those homework questions
- HOMEWORK BANKS of other potentially valuable homework questions which were not used in the course.
- TUTORIALS** developed by undergraduate Darren Tarshis, Stephanie Chasteen, and Steven Pollock, revised by Dubson and Kinney, and tutorials PRE-TESTS developed by Steven Pollock and Rachel Pepper.

- PUBLICATIONS on this work, including four posters and five papers.
- TRADITIONAL ASSESSMENTS including midterm and final exams
- CONCEPTUAL ASSESSMENT. The Colorado Upper-Division Electrostatics (CUE) diagnostic was developed and administered at several universities, see below.

The course archive materials were made available online on the website (per.colorado.edu/Electrostatics), on our website (http://www.colorado.edu/sei/departments/physics_3310.htm), at the Physical Science Resource Center for the AAPT (<http://www.compadre.org/psrc/items/detail.cfm?ID=7891>), and promoted at the AAPT and PERC meetings and met with considerable interest. A total of 53 external faculty have indicated an interest in using the materials, and to date we know of at least 17 who have done so. This enthusiastic response to our materials is a strong indicator of the need within the physics community for research-based materials for teaching upper-division E&M. We developed a preliminary survey of users of the materials, which indicates that most instructors became aware of our materials through research conferences and publications, though we are also aware of some who have located our work through internet search engines that directed them to our website. That survey suggests that most users are new instructors, seeking pedagogical guidance. Thus, these materials represent a valuable opportunity to impact the next generation of college instructors such that they develop interactive teaching strategies based on research.

Another important aspect to disseminating and sustaining the course transformations is providing an organizational structure that is easily navigated and lends itself to a-la carte use of individual resources, so that instructors may tailor their use of the materials to their particular class and teaching style. Overall reactions to the organization of the materials – by instructors at CU and outside -- was positive. The course archive system has recently been recommended for adoption among other SEI departments, and a document detailing the organizational structure and rationale was created to assist other departments in emulating it. The per.colorado.edu/Electrostatics site was put together in the Spring and Summer of 2012 to provide a comprehensive archive of our material. The interface helps to facilitate browsing the materials quickly and easily by category or by topic. This makes it even easier for users to choose individual resources a-a carte. The new site is also monitored with Google Analytics allowing us to gather detailed information on the frequency and location of users as well as information on how they interact with the site.

The six CU instructors were interviewed individually for one hour, twice during the course of each semester of instruction up to 2011. This allowed us to assess the efficacy of our method of course transformation, sustainability of the reforms, and gather feedback on the organization of course materials.

c. Colorado Upper-Division Electrostatics (CUE) Assessment

The CUE is a conceptual assessment that examines student learning in aspects of the course not typically tapped in traditional (exam) assessments. This exam enables CU and other institutions to assess the impact of different methods of instruction on student understanding in this course, providing an independent measure of student learning for

comparison across courses and over time. It also provides a window into student thinking on topics of the course, by analysis of student answers and patterns of responses.

The CUE is an open-ended assessment developed based on faculty learning goals and common student difficulties. It is a 17-question test consisting of written explanations, conceptual reasoning, sketching, graphing, and a few multiple choice questions. A pre-test was developed based on a reasonable subset of the post-test. The pre-test takes 20 minutes of in-class time and the post-test takes 50 minutes of in-class time.

A detailed grading rubric was developed, along with classification of common student errors. Two independent graders used the rubric to score a set of 36 student exams. Interrater reliability was very high, with an average score difference of just 1.4%. Graders agree within 10% of the overall CUE score on about 10% of the exams. CUE score is significantly correlated with the student's overall score in the course based on traditional measures such as homework and exams. It shows good item discrimination, as indicated by high correlation of individual test items with the overall test score. Cronbach's α for the items on the CUE is 0.82, indicating strong internal statistical reliability. The CUE has been validated through think-aloud interviews and faculty feedback – that work is ongoing, and a publication on the CUE is in development.

The CUE post-test was given to 9 semesters of E&M I students – Fall 2007 (taught traditionally: STND), and the 5-semester of transformed (PER) courses: Spring 2008 (the first semester of transformations), Fall 2008, Spring 2009, Fall 2009, Spring 2010 (successive iterations of transformations), Spring 2011 (semi-transformed), Fall 2011 (semi-transformed), and Spring 2012 (transformed). The CUE post-test was also given in several external institutions, and graded for nine courses in six outside institutions. In Fall of 2011, the CUE was also given to 12 graduate students from CU. All courses with CUE scores above the mean used interactive engagement techniques, such as clickers. The CUE post-test scores of students in courses using PER-based instructional techniques are statistically significantly higher than all the courses using a standard lecture format at CU and elsewhere (with the exception of Non-CU-STND2, which matches the lower-scoring PER-based courses). Taking each student as a data point, the average CUE score is higher in PER courses ($57 \pm 1.3\%$) than in STND courses ($44 \pm 1.6\%$, $p < 0.001$). Taking each course as a data point, the same result holds ($61 \pm 4\%$ PER vs. $40 \pm 4\%$ STND, $p < 0.001$). If the CUE were a graded exam, this would be comparable to a gain of two letter grades. The graduate students averaged a $62 \pm 4\%$.

This provides some of the first evidence that interactive engagement techniques improve student learning, even at the upper division. Overall, these results suggest that the interactive techniques were consistently successful, over 7 semesters at CU and at three external institutions, in improving students' facility with the concepts and problem-solving methods of junior E&M. As the CUE was developed based on the learning goals (Figure 1), this suggests that we achieved some measure of success in our aim of supporting the cognitive skills of developing physicists. Examination of the demographics of individual courses shows that these results cannot be easily explained by factors related to the students or instructors, such as incoming GPA, incoming score on

the introductory conceptual assessment (BEMA), or instructor experience. Indeed, some of the highest scores on the CUE occur in classes where the instructor had no prior experience teaching the course. The robustness of these results over time, across instructors, and across institution also suggests that the course transformation effects can be sustained from instructor to instructor and across institutions.

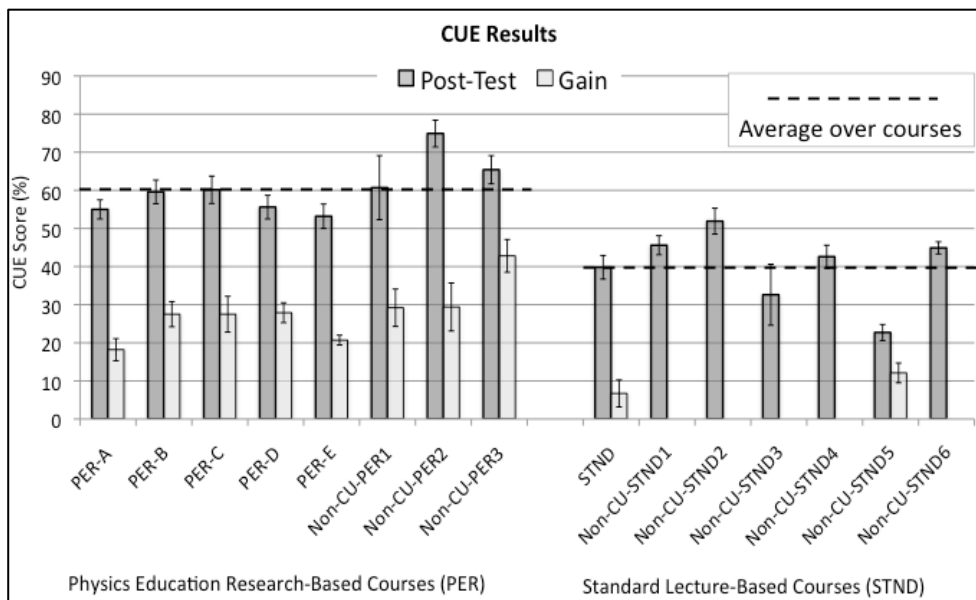


Figure 1. CUE scores across institutions for N=382 students. “Post-test” represents course average score (% correct) for the subset of CUE questions given in common across all exams (88 out of 118 possible points). “Gain” represents the course average (out of 100%) for the difference between the pre-test (60 points) and the matched subset of the post-test (i.e., 60 points). Due to the lack of pre-tests for PER-A and STND, pre-test scores are estimated (and thus gain scores are effective) based on the stable pre-test scores for other semesters of PHYS3310. Number of respondents varies from 5 to 138 in a given course. PER courses are not listed sequentially (i.e., PER-A is not the first semester of the transformation). Error bars represent 1 standard error of the mean.

Scores on the pre-test are consistently low (30%), except for the scores for student at a private liberal arts institution (C-IE in the figure above), who were taught using the materials developed in this project. Thus, the CUE can differentiate between students with different levels of preparation, and students using our materials experience similar levels of learning gains on the CUE from pre- to post-test, regardless of initial levels of preparation. The CUE is also capable of differentiating between different types of course instruction.

d. Course Data

The 6 courses at CU were compared on several measures to assess the impact of the transformations. Students in these courses were, for the most part, similar in terms of

incoming GPA, gender, and major. Complete comparisons across all courses are reported below.

| | | PER-A | PER-B | PER-C | PER-D | PER-E | STND |
|--|------------|--------------------------------|----------|-------|----------|----------|----------|
| Pedagogy | | Research-based transformations | | | | | Lecture |
| Instructor | | PER1 + Non-PER1 | Non-PER2 | PER2 | Non-PER2 | Non-PER3 | Non-PER4 |
| Course N | | 48 | 37 | 22 | 56 | 46 | 41 |
| Major (%) | PHYS | 48 | 49 | 50 | 55 | 57 | 39 |
| | EPEN | 27 | 22 | 36 | 30 | 20 | 34 |
| Females (% of class) | | 27 | 26 | 25 | 16 | 11 | 25 |
| Ave lecture attendance (% of class) | | 86 | 77 | 94 | 77 | 76 | 73 |
| Ave students attending a tutorial (% of class) | | 30 | 42 | 44 | 37 | 38 | N/A |
| Ave students attending a help session (% of class) | | 30 | Unknown | 58 | Unknown | Unknown | Unknown |
| FCQ | Instructor | 85 | 97 | 98 | 95 | 97 | 87 |
| | Course | 80 | 90 | 92 | 87 | 85 | 85 |
| Demographics | | | | | | | |
| Cumulative GPA | | 3.1 | 3.1 | 3.1 | 3.2 | 3.2 | 3.1 |
| Physics GPA | | 3.0 | 3.1 | 3.0 | 3.2 | 2.9 | 2.9 |
| BEMA | Post-102 | 61 | 58 | 69 | 58 | 55 | 60 |
| | Post-301 | 66 | 63 | 71 | 63 | N/A | 64 |

Table 1: Course demographics. Courses involved in this study, not in chronological order. PER 1 and 2 are different PER faculty. Non-PER 1-4 are different non-PER faculty. “EPEN” = Engineering Physics, and “PHYS” = Physics. Attendance is an average of the attendance on the days that the FCQ and CUE were administered, and the clicker attendance scores (where applicable). Students who missed two exams and/or did not take the final exam were excluded from study, and students who took the course more than once (without failing/dropping) were included only in the first enrollment. “FCQ” = Faculty Course Questionnaire given at the end of the semester, given out of 100%. “Instructor” = “Rate this instructor compared to all your other university instructors.” “Course”= “Rate this course compared to all your other university courses.” Cumulative and Physics GPA are calculated prior to the start of PHYS301. “BEMA” = Basic Electricity and Magnetism Assessment, given as a Post-test after introductory physics (PHYS 1120) and Junior E&M I (PHYS 3310).

We gave some exam problems in common among the courses. The course transformations did not hurt students’ ability to perform mathematical calculations (e.g., separation of variables, direct integration), but they did not particularly improve this skill, as measured by these traditional exam problems. However, the new course approach did appear to improve students’ skills in two key areas on exams: The ability to provide

reasoning behind the answer, and to properly identify the most suitable method for solving a particular problem.

Overall, students liked the PER-based courses, as judged by end of term attitude surveys. Students engaged more fully in the PER-based courses, as judged by improved attendance at lecture, attendance at optional tutorial and homework help sessions, and time spent on homework. However, in one course (PER-A), student attitude data was less favorable. It appeared that this instructor may have paid less attention to student difficulties at the junior level, and students did not feel that lecture prepared them for challenging homework. So, these course materials are not turn-key, and implementing the pedagogical approach requires substantial instructor involvement and pedagogical sophistication.

Lecture, clicker questions, and tutorials were most popular among students. Students (with the exception of PER-A) felt that the lecture was well-connected to homework and provided adequate instruction in mathematical techniques. While whiteboards were poorly rated by students, we have reason to believe that this tool could be more valuable if implementation were optimized for effectiveness. No clear effect of clicker questions or lecture could be discerned. Tutorials – in addition to being favorably rated by students – also contribute positively to student learning (as measured by the conceptual assessment, the CUE), even when background variables are taken into account by multiple regression. Judging from student comments, we successfully provided students support in honing their problem-solving skills through carefully designed homework and additional opportunities to interact with one another and instructors in tutorials and help sessions.

Students are not the only participants positively affected by the course. Several aspects of the course – particularly clickers, tutorials, and homework help sessions – provide a valuable opportunity for instructors to gain insight into student thinking. These course elements provided opportunities for instructors to discuss with and listen to students, providing a window into student thinking. This formative assessment is not typically available in a lecture-based course, and allows the instructor to better match the course to the students. One (non-PER) instructor who used the materials contrasted this approach with a traditional course: “What you tend to do teaching in the traditional way is, there are three or four students, maybe only one sometimes, who’s on top of everything, answers all the questions, is smiling, is happy, and you get a rapport with the students who talk to you and you feel like things are going great.” The developed materials (clicker questions, tutorials, and homework help sessions), he claimed, help him to “talk more directly to and hear, listen to, the average student.” These techniques also help to change the culture of the classroom. One instructor (teaching a similarly transformed quantum mechanics course) indicated that clickers helped to frame the class as an interactive environment, essentially breaking the ice so that it was easier to generate conversation in the class. One non-trivial outcome is that the instructors were very positive about the experience, which can result in dissemination and sustainability of the transformations: “I enjoyed it immensely,” reported one (non-PER) instructor. “Next time you need somebody else to do it, don’t hesitate to call.”

e. Physics graduate survey

In order to gather more information about student perceptions of our upper-division courses, over 250 alumni of the physics program were surveyed about their current careers as well as their impressions of the CU physics program. About 25% (67 respondents) completed the survey, most of whom had graduated between 2003 and 2007. Results from the survey are shown below:

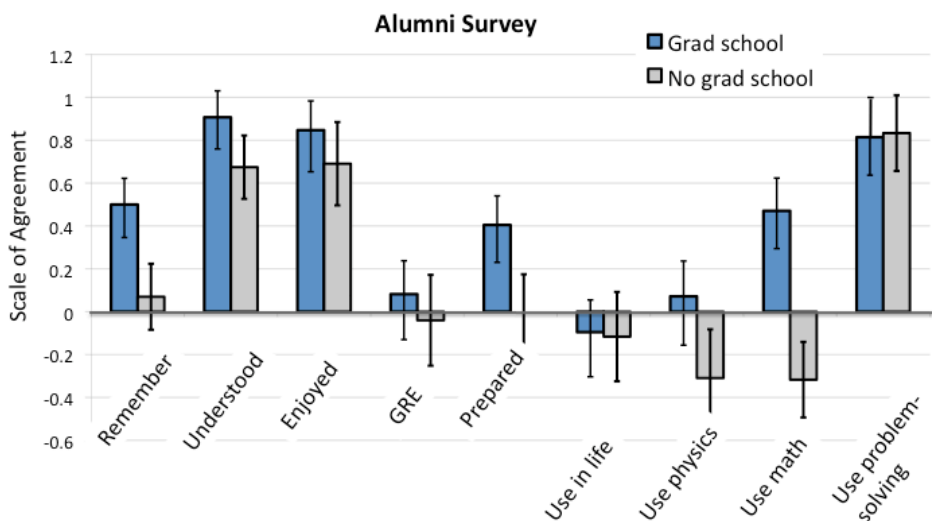


Figure 2. Alumni survey results. Alumni were asked to answer on the basis of their graduate degree program (if ever enrolled) or current job (if never enrolled in graduate school). Questions were rated on a scale of 1-5 (strongly disagree to strongly agree), and then converted to an scale of -2 (strongly disagree) to +2 (strongly agree) by subtracting 3 from the overall average. Questions were as follows: (1) I remember what I learned in PHYS301, (2) I understood the material in PHYS301, (3) I enjoyed PHYS301, (4) PHYS301 prepared me well to take the GRE (if applicable), (5) PHYS301 prepared me well for my job or graduate school, (6) I use something I learned in PHYS301 in my life outside of my primary job or graduate research, (7), I use the physics I learned in PHYS301 in my primary job or graduate research, (8) I use the math I learned in PHYS301 in my primary job or graduate research, (9) I use the problem-solving techniques or approaches that I learned in PHYS301 in my primary job or graduate research.

Graduates were employed in a wide variety of jobs, especially in industry and finance. Fewer continued on to graduate school than had been expected, with a total of 35% never having attended graduate school. Many recurrent themes were noted with respect to upper-division E&M and Quantum, such as an appreciation of the intellectual challenge of the course, but a dissatisfaction with the focus on mathematics at the expense of conceptual understanding, and a disconnect from real-world examples. Alumni who continued on to graduate school found the material of both E&M and Quantum to be more relevant to their careers and lives. These results provided useful information about our graduates and how we might serve their needs through these course transformations. In particular, the following questions were posed to the undergraduate committee, based

on these results: (1) Are we meeting the needs of those who do not attend graduate school? (2) Are we focused appropriately on problem-solving and critical thinking? (3) How do we increase continuity in two-semester courses? (4) How can we support supplemental activities from instructors? And (5) Can and should we increase the conceptual focus in upper-division?

3. *Quantum Mechanics I (PHYS 3220)*

Quantum Mechanics 1, PHYS 3220, is required for completion of the BA in Physics and Astrophysics as well as for the BS in Engineering Physics – about 72% of the course is populated by these majors. The remaining students are comprised of mathematics majors (10%), other natural science majors (2%), non-physics engineering majors (11%) and other miscellaneous and undeclared majors (5%). Typically, this course is taken by juniors and seniors, and the enrollment is 30-60 students. Several faculty have taught this course in the past six years. Recent instructors have been Eric Zimmerman, James Shepard, John Price, (twice), Tom DeGrand (twice), Kevin Stenson, Oliver DeWolfe, Steven Pollock, and Andreas Becker. For the Fall 2008 semester, the course was team taught by Steven Pollock and Oliver DeWolfe. In six of the last twelve semesters, the same instructor taught PHYS 3220 and the second semester course, PHYS 4410.

In Spring 2009 Oliver DeWolfe taught the course, using the reforms which were developed over the two previous semesters. In Fall 2009, the course was taught by Andreas Becker. While he took a different approach to the material, he used many of the reformed course materials and also developed new materials to support his curricular approach. The course is being taught in the Spring 2010 semester by Murray Holland who is using mainly the approach and the materials developed by Pollock and DeWolfe.

Activities in Quantum I include:

a. The Quantum Mechanics Assessment Tool (QMAT)

With the assistance of several faculty members, Steve Goldhaber has developed a post-test assessment tool based on learning goals, and has performed preliminary validation of the instrument through interviews with faculty and students. During development of the test, a total of 21 students were videotaped while they took versions of the test and explained their reasoning out loud. A total of 27 students took the test as an in-class diagnostic exam near the end of the Fall 2008 semester. As an incentive to take the test seriously, students were offered individual feedback on their strengths and weaknesses in areas such as quantum mechanics formalism and separation of variables. The test was revised and administered in both the Spring 2009 and Fall 2009 semesters. In all, a total of 89 CU quantum I students have taken the assessment. In addition, near the end of the Fall 2009 semester, the QMAT was administered at four outside institutions to a total of 113 students. This instrument will not serve as a pre-test, since most students have not previously been exposed to much of the content of the course.

b. Course Materials

All materials generated for PHYS 3220 will be available to future faculty who teach the course. One resource many have requested is a bank of homework and exam problems that

they can draw upon. These questions have been chosen and developed to align with the learning goals for the course, allowing faculty to provide students with assignments designed to develop a wider variety of student skills than those easily created by a single faculty member. Similarly, the concept/clicker questions developed for the course are provided as a ready-to-use resource for faculty. Steve Goldhaber has assembled a bank of exam questions given in PHYS 3220 over the last decade. Concept test questions developed by Mike Dubson, Steve Pollock, Oliver DeWolfe and Steve Goldhaber have been gathered and mostly organized by type of material. Currently, the course archive consists of:

- COURSE CALENDAR: sample course calendars
- STUDENT DIFFICULTIES organized by topic, as compiled from the literature and from observations in student interviews, homework help sessions, written homework, and tutorials over the course of 3 semesters.
- LEARNING GOALS: The faculty consensus goals developed from meetings and interviews with the faculty working group. These goals include overall course goals as well as goals for specific topics in quantum mechanics.
- CONCEPTTESTS (a.k.a. 'clicker questions') organized roughly by the chapters in Griffiths' textbook. Several hundred questions have been developed in all, annotated with class responses and instructor observations.
- LECTURE NOTES written by Steven Pollock and Michael Dubson.
- HOMEWORK ASSIGNMENTS: Significant work has gone into homework questions which not only develop computational proficiency with the new material but which also require students to engage in conceptual thinking and to make sense of their answers. The archive contains the homework assignments and solutions along with detailed observations of student performance for assessment of the value of those homework questions.
- TUTORIALS : Eight quantum tutorials developed by Steve Goldhaber, and Steven Pollock.
- PUBLICATIONS on this work, including a poster and two papers.
- TRADITIONAL ASSESSMENTS including midterms and final exams.
- CONCEPTUAL ASSESSMENT. The Quantum Mechanics Assessment Tool (QMAT) diagnostic was developed and administered at several universities, see above.

The course archive materials were made available online and promoted at the AAPT and PERC meetings and met with considerable interest. A total of 23 faculty have indicated an interest in using the materials, and to date we know of at least 4 who have done so with more planning on using them in the near future. In addition, some of the materials are being incorporated into a senior physical chemistry class in the chemistry department at CU.

4. Classical Mechanics and Math Methods I (PHYS 2210)

Classical Mechanics and Math Methods 1, PHYS 2210, is required for completion of the BA in Physics or Astrophysics and for the BS in Engineering Physics – these majors populate about 79% of the course. The remaining students are usually other natural science majors. Typically, sophomores take this course as their 4th course in the physics sequence, and the enrollment is 40-70 students. Several faculty have taught this course in the past six years. Recent instructors have been John Wahr, Shijie Zhong, Bill Ford, Meredith Betterton, and Anna Hazenfratz. In 2010, no intervention was made in the choice of faculty

teaching PHYS 2210 – John Wahr, who has taught the course many time taught in the spring and Alysia Marino, a new faculty member taught in the fall.

Dr. Pepper sat in on both John Wahr and Alysia Marino’s courses. In spring of 2010, though a transformed version of the course was not yet prepared, Professor Marino independently decided to implement a number of PER-based techniques with help from Dr. Pepper. These techniques included the clicker questions in class, Intermediate Mechanics Tutorials (available from the University of Maine) in class, homework help sessions, and some conceptual homework and exam questions. The official SEI course transformation of PHYS 2210 started in the spring of 2011 with Steve Pollock and Ana Maria Rey co-teaching the course. Transformation of the course has continued through the spring of 2013 with Dr. Marcos Caballero facilitating the development and refinement of course materials. Instructors teaching a transformed version of this course now include Steve Pollock, Alysia Marino, and John Bohn. Kyle McElroy is teaching a minimally transformed version of the course this semester (spring 2013) because enrollment swelled to 90+ students requiring the use of a temporary space. McElroy is the sole instructor for the course; Dr. Caballero observes the course weekly.

Activities in PHYS 2210 include:

- a. Creation of learning goals

A faculty working group facilitated by Dr. Pepper created both broad-scale and topical learning goals for PHYS 2210. The goals are listed online (http://per.colorado.edu/ClassicalMechanics/learning_goals.html Course Materials)

- b. The Colorado Classical Mechanics/Math Methods Instrument (CCMI)

With the assistance of several faculty members, Dr. Pepper began development of both a pre and post-test assessment tool based on the most important learning goals selected by the faculty working group. Initially, the instrument contained 15 questions split into two exams with roughly 10 questions appearing on each version. Through discussions with faculty, Dr. Caballero culled the exam to 11 questions. The CCMI has been administered as a pre- and post-test each semester since the transformation began in spring 2011.

Dr. Caballero conducted interviews with 8 students who had recently completed PHYS 2210 to refine the wording of each of the 11 questions. Data from interviews also suggested why students answered question in particular ways. The locally validated instrument was then administered at CU and at 5 partner institutions (Table below) who are not presently using course materials developed at CU.

| Institution | Type |
|-------------|--|
| 1 | Private, liberal arts college |
| 2 | Private, liberal arts college |
| 3 | Public, research university (BS granting) |
| 4 | Public, research university (PhD granting) |
| 5 | Prestigious, private, liberal arts college |

Feedback from instructors teaching outside of CU was overwhelmingly positive. Instructors found value in the instrument and how their students responded to it. Even instructors teaching a single-semester classical mechanics course believed the instrument was valuable. According to these instructors, the CCMI covers the core concepts they want students to leave their course knowing. However, 2 questions were deemed inappropriate for most partner institutions; most instructors do not teach a combined classical mechanics and math methods course. The 2 questions were moved to the end of the instrument and are now optional. The score that students earn on the questions does not contribute to official calculated score, and instructors may choose to neglect them completely. The finalized version of the instrument was first given in fall of 2012.

Scoring the assessment reliably has been the focus of this semester (spring 2013). Developing a rubric that instructors can use easily with no training has produced a simple rubric that evaluates mastery. Most questions are graded for correctness only with some partial credit assigned for very small mistakes. This reliability of this rubric is currently being established using student work from the fall 2012 version of the CCMI.

Capturing the nuances of student work is equally important, but is not the role of a grading rubric. A parallel coding rubric will be developed for researchers interested in capturing these nuances. Dr. Caballero plans to complete the development of the CCMI in the next year including establishing its reliability. Future work will use the CCMI to evaluate instructional methods at CU and elsewhere.

b. Course Materials

Between spring 2011 and summer 2012, a set of course materials were developed and organized by Alysia Marino, Steven Pollock, and Marcos Caballero. All materials were based on detailed student interviews as well as detailed observations of lecture and group work. These materials include:

- COURSE CALENDAR, including activities and covered material
- STUDENT DIFFICULTIES pertinent to each chapter of the textbook, as compiled by observations in student interviews, homework help sessions, written homework, and tutorials over the course of 4 semesters.
- LEARNING GOALS for the course overall, and for individual chapters, developed from meetings and interviews with the faculty working group
- CONCEPTTESTS (a.k.a. 'clicker questions') for individual chapters. A few hundred questions have been developed in all, annotated with class responses and instructor observations.
- LECTURE NOTES
- CLASS ACTIVITIES: Lists and descriptions of interactive activities for each topic area in the course, including lecture demos, kinesthetic activities, whiteboards, and group work.
- HOMEWORK ASSIGNMENTS and solutions, and detailed observations of student performance for assessment of the value of those homework questions. Computational homework questions for which students use Mathematica are also included.

- HOMEWORK BANKS of other potentially valuable homework questions that were not used in the course.
- TUTORIALS developed by Rachel Pepper, Marcos Caballero, Alysia Marino and Steven Pollock.
- TRADITIONAL ASSESSMENTS including midterm and final exams
- CONCEPTUAL ASSESSMENT. The Colorado Classical Mechanics/Math Methods Instrument (CCMI) diagnostic was developed and administered at several universities, see below.

Dissemination of these materials is facilitated through course materials website (<http://per.colorado.edu/ClassicalMechanics/>) developed by Dr. Caballero and now used for E&M 1, E&M 2, and Quantum Mechanics. The website simplifies the navigation of course materials, allows incremental and full downloads, and tracks web traffic automatically. Since the launch of this website in summer 2012, it has had 839 unique visitors and 45 visitors have downloaded the entire archive.

5. Optics and Modern Physics Laboratory (PHYS 3340/4430)

The Optics and Modern Physics Laboratory, PHYS 3340/4430, is the last of four lab courses in the undergraduate physics curriculum. The course is usually taken by Juniors and Seniors. The course is an elective for Physics majors, and satisfies a required research experience for Engineering Physics majors. Typically about 25 students take the course per year. Typically about 70% are Engineering Physics, and about 30% are physics majors. The course covers experimental techniques in optics and modern physics.

In response to significant faculty interest, the course is being redesigned by Professor Heather Lewandowski (Physics/JILA) and a post-doctoral researcher, Ben Zwickl. The SEI has contributed support for the first stages of the course redesign. Two years of NSF support (Heather Lewandowski, PI) will begin in the summer of 2011. The grant is provided through the Transforming Undergraduate Education in STEM (TUES) program. The funding is for a research-based redesign of the CU upper-division physics lab courses.

Lab courses are under scrutiny because they require expensive equipment, have low student teacher ratios, take lots of time, and don't always have clear education value. This project has as major goals to establish clear learning objectives, assessments, new lab guides, and a better sense of the role of lab courses in the curriculum. Faculty, students, and industry employers will all provide input as we redesign the course.

Background research and preliminary work on learning goals took place in November and December of 2010. A list of activities and goals for 2011 are listed in the section on goals below.

C. Departmental faculty development and involvement in SEI efforts.

1. E&M I (PHYS 3310) working group

The faculty working group for E&MI was convened twice this year, to present results from the alumni survey and the course transformations. The results of the alumni survey were

also presented at the faculty meeting at large, and distributed to every faculty member. Some members of the faculty working group for 3310 were consulted individually as the CUE post-test was revised.

STF's met with the instructors for 3310 weekly, to provide ongoing course support and collectively reflect on observations and outcomes related to the course -- Dr. Chasteen with Dr. Kinney in Spring 2009, and Dr. Pepper and Dr. Chasteen with Professor Schibli in Fall 2009.

Dr. Chasteen, Dr. Goldhaber and Dr. Pepper interviewed the five faculty (DeWolfe, Pollock, Dubson, Kinney and Schibli) on the process of the course transformations. These results are in the process of being reviewed and compiled, potentially for publication.

Dr. Chasteen gathered some materials for the second semester of the course (E&M II: PHYS 3320), and discussed course pedagogy with Professor Charles Rogers. After that course, Dr. Chasteen discussed outcomes and pedagogy with Professor Rogers, and shared it with the next instructor, Professor Kinney.

Dr. Chasteen discussed the implementation of tutorials (developed at another university) in sophomore-level Mechanics with Professor Betterton – she and Dr. Pollock assisted Dr. Betterton in implementing two of those tutorials in class.

2. Quantum Mechanics I (PHYS 3220) working group

The faculty working group for quantum mechanics I met in April to review the QMAT before the administration at the end of the semester. Based on feedback received at this meeting, several minor changes were made and the final set of questions was selected.

3. Classical Mechanics/Math Methods I (PHYS 2210) working group

Dr. Pepper recruited a faculty working group and facilitated 3 meetings over the summer of 2010 and 4 meetings in the fall of 2010. In the summer, the faculty agreed on what topics the 2210/3210 course sequence would cover, and in which semester each topic would fall. Broad course-scale learning goals were also determined. In the fall, topical learning goals were discussed and prioritized for inclusion in a conceptual post assessment. Some diagnostic questions were written and improved with help from the faculty working group. Nineteen faculty (4 of whom were PER faculty) participated in these working group meetings with an average attendance of 9 faculty members at each meeting. Each faculty member who participated attended on average about half of the meetings.

Prior to the creation of the faculty working group and its meetings, Dr. Pepper interviewed several previous instructors of PHYS 2210 and PHYS 3210, including some faculty members who did not later participate in the working group meetings.

4. Optics and Modern Physics Lab (PHYS 3340/4430) working group

Professor Heather Lewandowski (Physics/JILA) has been the driving force behind this project. She is motivated by personal experience teaching the lab class, and has a strong desire to create outstanding lab classes at CU. She has successfully applied for NSF funding through the TUES program and is collaborating with the Physics Education Research Group in addition to leading a lab in Atomic Molecular and Optical Physics.

Ben Zwickl, the post-doctoral researcher on the project, will involve faculty in the redesign of the Optics and Modern Physics Lab through individual interviews, and later through faculty working groups. It is expected about 15 individual interviews will be conducted and a faculty working group of about 6 will be established in the spring of 2011.

5. Faculty impact interviews

The four CU instructors from the Fall 2008 and Spring 2009 semesters were interviewed individually for one hour, twice during the course of each semester of instruction. This allowed us to assess the efficacy of our method of course transformation, sustainability of the reforms, and gather feedback on the organization of course materials. These interviews will be the subject of future analysis, but key results include:

- The STF's involvement in the course (through discussions and feedback) is cited as being very helpful, underlining the utility of a dedicated postdoc in course transformations
- The availability of transformed course materials appears to promote greater interactivity in instructors' pedagogy during the course, XXX
- Co-teaching with an experienced PER instructor appears to be transformative for non-PER instructors, who report learning a great deal from the experience. Instructors using the materials, without co-teaching, appear to receive less educational benefit from teaching the course.
- Both PER and non-PER co-teachers reported benefits from co-teaching and enjoyed it immensely as a professional experience. Non-PER co-teachers learned a great deal from the experience, such as learning to write clicker questions that were more integrated with lecture, and how to facilitate productive student conversation in the classroom.
- Instructors found course materials to be very useful (in particular student difficulties, the tutorials and clicker questions), and, for the most part, would not have had the time to develop these during course instruction. Overwhelmingly, they would use the course materials if teaching the course again.
- Various recommendations were given for organization of course materials to be user-friendly and easy to navigate
- Course instruction with the materials appears to take more time (not less) due to the increase in the number of materials to reference prior to planning lecture, though opinions vary by instructor.
-

D. Goals for 2013-2014

1. Goals for work on 3310:

- Work on this course is likely to go into a slight hiatus as Dr. Pepper shift attention to Classical Mechanics and Dr. Chasteen focuses on other responsibilities.
- Continue to support and promote the use of these materials at CU and other institutions by maintaining the online interface.
- Continued work on identifying and characterizing student difficulties with topics in E&M.

2. Goals for work on 3220:

- Analyze results from three administrations of the QMAT at the University of Colorado as well as those from four outside institutions. Use these results along with results from

exams, homework assignments and tutorial pre-and-post tests to summarize our findings about student learning difficulties in upper-division quantum mechanics.

- Conduct inter-rater reliability testing in order to refine the rubric and to produce a QMAT instructor guide so that outside administrators can reliably assess the performance of their students.

3. Goals for work on 2010:

Should funding continue for this transformation project, the SEI should:

- Continue to run transformed versions of PHYS 2210, including creating new clicker questions, homework questions, in-class activities/tutorials, exam questions, and pre-class activities.
- Add materials to online archive and continually refine online format.
- Administer the CCMI at CU-Boulder and at other institutions.
- Investigate student difficulties through weekly homework help sessions, individual student interviews, and small-group student interviews.
 - Broaden investigations to include longitudinal studies of student difficulties.
- Write papers (PERC, AJP, and PRST-PER) about the results of this work including research into student difficulties, development of and results from the CCMI, and the transformation process.

4. Goals for 3340/4430 Optics and Modern Physics Lab:

- Establish consensus learning goal with faculty for the advanced lab course.
- Observe, interview, and survey students taking 3340/4430 during the spring of 2011.
- Review literature and practices at other colleges and universities for assessment in lab courses. Establish assessment methods for 3340/4430. It is essential we use assessments which provide evidence of learning in the lab, and provide feedback to students so they can improve their own scientific abilities.
- Create revised laboratory experiments. This could involve new lab equipment, rewritten lab guides, rubrics for student lab reports and lab notebooks, etc.
- Develop tutorials in experimental physics for the lecture part of the course. Tutorials could involve data analysis, plotting, computer control of experiments (LabVIEW), design of experiments, scientific writing, and other topics relevant to laboratory work, but which are better suited to being taught in a classroom.
- Write up a PERC paper on the process of establishing learning goals at CU, and a review article on assessments in lab courses.