

**2010 Annual Report**  
**for the**  
**CU Science Education Initiative**

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(with budgeting through Dec. 31, 2010)

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## 2010 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.

As the SEI approaches the end of its 5<sup>th</sup> year, the departments and faculty participating in the SEI have indeed changed substantially.

### a. Impact on Faculty

Across the entire project, over 100 faculty in 5 departments (CHEM, GEOL, IPHY, MCDB, PHYS) have been impacted by the SEI with over 94 having modified their instruction based on the SEI efforts. Over 50 faculty have taught a course with the support of an STF, providing collaborative opportunities that can have a deep impact on faculty practice. Learning goals have been used or developed by (at least) 70 faculty, 64 have used information on student thinking to help guide their teaching, and 54 have used pre/post surveys of student learning. These results indicate that many faculty are engaging in research-based teaching methods.

Since the SEI began, over 50 faculty have started interspersing conceptual questions in class and using clicker technology to engage *all* students in actively thinking about and discussing the material. In addition, 60 of the faculty who were already using clickers have improved the pedagogy of their use and over 80 have used new course materials. Over 50 faculty have incorporated other interactive engagement methods in class – typically some form of small group activities either in lecture or recitation.

In addition to these changes in classroom practice, faculty are also gaining opportunities to increase their engagement in educational issues. The majority of faculty in SEI departments see the STFs as helpful resources, and seek them out for information about education topics. The majority of faculty (86) report that they either have more conversations with their fellow faculty about teaching, or that the nature of existing conversations has changed. Additionally 9 non-education-research faculty have collaborated with STFs on peer-reviewed publications on SEI work, and the SEI project has informed over 8 NSF CAREER proposals across departments, indicating a deep impact with the potential to affect long-term faculty identity regarding involvement in the scholarship of teaching and learning.

## **b. Impact on Students**

After 5 years, the SEI project has impacted at least 53 of the undergraduate courses in these 5 departments, with the STFs working very closely with faculty on 25 of these courses. There are at least 20 courses with explicit learning goals developed by faculty consensus and another 19 courses where individual faculty have created such goals. Explicit learning goals that define what students should be able to do after taking a course benefit the faculty and departments, and the students have expressed in surveys how helpful they find the explicit goals.

The 25 courses which have been the main focus of SEI STFs impact about 7600 student-course-experiences per year. The additional 28 courses in which STFs have had partial involvement or consulted with faculty impact an additional 4700 student-course-experiences per year. In the focus courses, STFs work with faculty to carry out the three-stage process described above. Validated independent assessments of learning have been developed in 18 courses and are in development for another 6 courses. These assessment tools are guiding and providing proof of the improvements in student learning and hence teaching.

In summary, current and future students in these courses 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.

## **c. Impact on departments and the university**

The SEI departments are now defining far more clearly what students should learn in their department's courses and measuring how well these goals are being met, as well as changing their curriculum and pedagogy to improve student learning. In the 5 departments, over 96 faculty have been involved in setting course learning goals, more than 70 faculty have modified learning goals or content coverage in their courses, and more than 70 faculty have specifically used information on student thinking acquired by the STFs (through interviews, assessments, observations, surveys, etc.) to improve and guide their teaching.

By the faculties own account, the project has changed departmental culture. Discussions about teaching, learning, and departmental courses are much more frequent among the faculty and are now integrated into formal departmental structures such as faculty meetings. Faculty overwhelmingly report that the SEI has had a positive impact on their department.

The SEI work has also served as the foundation for 7 NSF-CCLI/TUES proposals across 5 departments, providing a mechanism for long-term impacts of the program on departments and the university. The SEI is also a member of the campus-wide Integrating STEM (iSTEM), which brings together existing efforts in STEM education at the university; joint SEI/iSTEM annual meetings have provided opportunity to expand the audience of each program to a wide variety of STEM departments.

#### **d. Establishing CU as a leader in STEM education**

The SEI project has attracted national attention as a leading effort in science education reform. Wieman has given over 20 invited talks highlighting the CU and UBC SEI efforts. In Summer 2008, Wieman was selected as a keynote speaker for the Facilitating Change in Undergrad STEM Conference, recognizing the progress that is being made at University of Colorado in this regard. In September, 2010 Dr. Wieman was selected to serve as the Associate Director for Science at the White House Office Science and Technology Policy, bringing additional national attention to the CU STEM education efforts, as well as acknowledging his role in transforming science education through the SEI.

In addition, the department-based STFs regularly give presentations at national meetings within their disciplines, and are being recognized for advancing the college-level science education work in these disciplines. Several STFs have been asked to serve as advisors on national boards or projects examining education related issues in their discipline. As STFs have completed their positions in the SEI, many have moved on to academic positions in science and science education at a wide variety of institutions: Thus, the SEI has impacted the career paths of these young scientists, and additional institutions are being exposed to the SEI philosophy of education and educational transformation.

The SEI project is also gaining recognition through a number of peer-reviewed publications. To date, a total of 33 peer-reviewed papers have been published on SEI research and course transformations. With a paper in *Science* magazine, Tin Tin Su (MCDB faculty), Michelle Smith (STF), Wendy Adams (SEI Central), and others received widespread national attention for establishing the importance of the pedagogical approach when using clickers. Stephanie Chasteen (STF), along with directors Carl Wieman and Kathy Perkins published an article detailing the SEI model of course transformation in the *Journal of College Science Teaching*, and co-directors Carl Wieman, Katherine Perkins and Sarah Gilbert also published a case study of the SEI efforts in *Change* magazine this year. Katherine Perkins along with STF Michelle Smith published an article about the value and process of defining learning goals in *Microbiology Australia*. These efforts all help to bring the SEI model to a broader audience.

The assessments and curricular materials generated by the SEI are also available free on the web, and reports indicate that many of these materials are being used by instructors nationally and internationally to improve instruction and assess student learning.

The SEI project has also generated several teacher guides and short white-papers on various research-based teaching practices. The SEI *Clicker Resource Guide: An instructor's guide to the effective use of personal response systems ("clickers") in teaching* is fast becoming a staple in training teachers on effective use of clickers, and is now being disseminated by i>clicker. Eight videos highlighting the pedagogical benefits of clickers and one video on group work have been produced, capturing the enthusiasm of faculty and student users at CU. These videos have been disseminated widely, and are used nationally by instructors and faculty developers wishing to demonstrate effective pedagogy, and have also been licensed for use by i>clicker. Pedagogical workshops on learning goals and clicker use have been developed and many faculty at CU have participated in these professional development experiences – beyond the campus, these materials have been widely accessed through our online workshop repositories, and served as a model for faculty developers at other institutions.

## **I. Overview of 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 2010, faculty involvement in the SEI, and departmental goals for 2011.

## **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.

Wendy Adams was hired on as Director of Research for the SEI in January 2008. A focus of the SEI efforts is to actively assess the effectiveness of various educational approaches and in this way establish approaches that work best. Wendy serves as an advisor and resource to the 12 Science Teaching Fellows (STFs) housed within the departments who are engaging in these research studies together with the faculty. Her expertise is in research study design, assessment instrument development and validation, interview methods, data analysis techniques, and framing and writing education research publications. She provides advice and feedback to the STFs and faculty in all of these areas, and thus facilitates the publication

and dissemination of faculty and STF findings from their studies. Dr. Adams left the SEI in early 2010 to pursue her teaching career.

Stephanie Chasteen, STF in Physics, began to spend a portion of her time on SEI Central Outreach activities in 2010, such as video production, faculty development, and exhibit booths at national conferences, to assist with bringing SEI materials and approaches to a broader audience both within the CU and nationally.

In addition, the SEI central project coordinator has been replaced. Marjorie Frankel is our new project coordinator. SEI central also employs two undergraduate workers (20 hours per week total) to assist all of the departmental STFs with survey administration and data processing.

## **B. Funding departmental-based efforts**

SEI funding has stabilized over the past few years, with increases in some departments. CHEM, GEOL, IPHY, MCDB, and PHYS are receiving funding with each of these departments able to hire 2 or 3 full-time PhD-level Science Teaching Fellows (STFs) to partner with their departmental faculty in carrying out their SEI goals as well as support some additional activities. Since January 2008, 4 new STFs have been hired (two in Physics, one in Geology, one in Molecular and Cellular Biology, and one in Integrative Physiology), bring the total number of STFs to 12.

With the activities in departments growing and more faculty becoming involved, there is an ongoing need for additional flexible funds to support short-term efforts. SEI departmental directors may propose to the SEI central program for additional funding for these projects (e.g. funding for faculty to participate in a 3-day summer working group to develop consensus learning goals).

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

## **C. Activities to support departmental-based efforts**

The SEI central staff (Carl Wieman, Kathy Perkins, Wendy Adams, Stephanie Chasteen, and Marjorie Frankel) support the departmental-based efforts in a variety of ways:

1. Wieman, Perkins, and Adams 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. Wieman and Perkins meet 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. Adams meets regularly with STFs to guide the structuring of the research studies that they are working on with faculty and to advise them on their efforts to publish their findings in peer-reviewed journals.
4. In order to promote the SEI efforts within each department and to make faculty aware of how their efforts fit into the national and international efforts to improve science

education, Wieman has attended faculty meetings in 3 of the departments where discussions focused on their SEI efforts and were lead by the departmental directors and STFs. In addition, Wieman and Perkins meet with selected new faculty or new chairs within each department each term.

5. To foster communication between departments, Wieman and Perkins hold monthly meetings with all the STFs – promoting STFs sharing with and getting feedback from the other STFs. In addition, STFs hold a biweekly reading group meeting to broaden and deepen their knowledge of education research.
6. The faculty directors communicate about the activities within each department at the advisory board meetings, held about once a month.
7. In May 2010, Wieman and Perkins hosted the fifth 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.
8. In the past year, the central SEI staff have organized several workshops for the STFs, including a series of workshop on statistics used in education.
9. Adams provides departmental support and communicates pertinent information related to expenses, hiring, and budgeting.
10. Frankel manages 2 undergraduate students (20 hours per week) who provide support services to the STFs, primarily posting and processing online student surveys.
12. Chasteen provides pedagogical support materials (videos, booklets) to STFs for use as they work with faculty on teaching innovations.

#### **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, including Chemistry, Geosciences, IPHY, and Physics. 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>

#### **E. Advisory board input**

In addition to central SEI staff, the SEI advisory board includes:

    Lorrie Shepard, Dean of the School of Education  
    Stan Deetz, Professor of Communications  
    Clayton Lewis, Professor of Computer Science  
    Mary Ann Shea, FTEP Director  
    Robert Parson, Professor of Chemistry and SEI CHEM director  
    Bill Byrnes, Professor of Integrative Physiology and SEI IPHY director  
    Paul Beale, Professor and Chair of Physics and SEI PHYS director  
    Steve Mojzsis, Professor of Geological Sciences and SEI GEOL director  
    Bill Wood, Professor of MCDB and SEI MCDB director  
    Sandra Laursen, CARTSS (Evaluation)

Over this past year, the advisory board has provided valuable discussions on several key areas, including: the evaluation of the success of the SEI, rate of progression through courses and how to know when work on a course is complete, and finding an appropriate balance of STF time spent on research versus implementation.

### **III. Highlights from the SEI Project**

The details of departmental activities are summarized in sections V-IX of this report. Here we highlight some specific results of the project as a whole which augment the results presented in the Executive Summary.

### **A. Publications and talks**

Over the past 5 years, STFs and faculty have engaged in assessing student thinking and learning and in developing and evaluating various approaches to teaching. While this work is conducted in the process of improving science education at University of Colorado, the results are of interested to the broader science education community and are publishable in peer-reviewed journals on science education.

Publishing the work has 3 important benefits: 1) it significantly influences the department faculty's view of the project outcomes and importance – peer-reviewed publications gives the results credibility that the faculty can relate to; 2) it directly engages some faculty in publishing peer-reviewed research in this area, providing an opportunity for deeper expertise in education research as well as recognition by faculty peers; 3) it prepares the STFs for their future career opportunities (as education research faculty, teachers, etc.); and 4) it highlights University of Colorado as a leader in science education reform efforts.

The following is a complete list of papers that have been published or are in preparation:

#### **SEI Central (2)**

Wendy K. Adams; Carl E. Wieman (2010). Development and Validation of Instruments to Measure Learning of Expert-Like Thinking. *International Journal of Science Education*, 1464-5289

Carl Wieman, Katherine Perkins, and Sarah Gilbert (2010). Transforming Science Education at Large Research Universities: A Case Study In Progress. *Change*.

#### **Geosciences (5)**

L. Arthurs and A. Templeton, (2010), “Coupled collaborative in-class activities and individual follow-up homework promote interactive engagement and improve student learning outcomes in a college-level Environmental Geology course,” *Journal of Geoscience Education*, vol. 57, p. 356-371.

#### **Integrative Physiology (2)**

Francoise Benay & Katharine Semsar (in preparation). “How Not To Lose Your Students in Concept Maps.” *Journal of College Science Teaching*.

Semsar, K., Knight, J.K., Birol, G., and Smith, M.K (in preparation) The Colorado Learning Attitudes about Science Survey (CLASS) for use in Biology. *CBE Life Sci Educ*

#### **Molecular, Cellular, Developmental Biology (11)**

Shi, J., J. Power, and M. Klymkowsky (in preparation). Revealing student thinking about experimental design and the roles of control experiments. *IJ-SoTL*

Shi, J., W.B. Wood, J. M. Martin, N.A. Guild, Q. Vicens, and J. K. Knight (2010). A diagnostic assessment for Introductory Molecular and Cell Biology. *CBE-Life Sci. Educ.* 9, 453-461.

Knight JK (2010). Biology Concept Assessment Tools: Design and Use. *Microbiology Australia* 31(1), 5-8.

- 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):32.
- Knight, JK and Smith, MK (2010). Different but equal? How nonmajors and majors approach and learn genetics. *CBE Life Sci Educ*, 9(1):34-44.
- Wood, WB (2009) Innovations in teaching undergraduate biology, and why we need them. *Ann. Rev. Cell & Devel. Biol.* 25, 93-112.
- Smith, MK, Wood, WB, Adams, WK, Wieman, C, Knight, JK, Guild, N, and Su, TT (2009). Why peer discussion improves student performance on in-class concept questions. *Science*, 323(5910):122-4.
- Smith, MK, Wood, WB, and Knight, JK (2008). The Genetics Concept Assessment: a new concept inventory for gauging student understanding of genetics. *CBE Life Sci Educ*, 7(4):422-30.
- Knight JK and Wood WB (2005). Teaching more by lecturing less. *Cell Biol. Educ.* 4, 298-310.
- Physics (12)**
- Stephanie V. Chasteen, Katherine K. Perkins, Paul D. Beale, Steven J. Pollock & Carl E. Wieman, (in press) "A Thoughtful Approach to Instruction: Course transformation for the rest of us", *Journal of College Science Teaching*
- Stephanie V. Chasteen, Rachel E. Pepper, Steven J. Pollock, Katherine K. Perkins (2010), "But Does It Last? Sustaining a Research-Based Curriculum in Upper-Division Electricity & Magnetism", *PERC Proceedings*, AIP Press.
- Steven J. Pollock, Stephanie V. Chasteen, Michael Dubson, Katherine K. Perkins (2010), "The use of concept tests and peer instruction in upper-division physics", *2010 PERC Proceedings*, AIP Press.
- Rachel E. Pepper, Stephanie V. Chasteen, Steven J. Pollock & Katherine K. Perkins (2010), "Our best juniors still struggle with Gauss's Law: Characterizing their difficulties", *2010 PERC Proceedings*, AIP Press.
- K Perkins and M. Gratny (2010). Who Becomes a Physics Major? A Long-term Longitudinal Study Examining the Roles of Pre-college Beliefs about Physics and Learning Physics, Interest, and Academic Achievement. *2010 PERC Proceedings*, AIP Press. (Best Paper Award)
- C. Wallace and S. Chasteen (2010), "Upper-division students' difficulties with Ampere's law", *Physical Review ST PER*, 6, 020115.
- Stephanie V. Chasteen and Steven J. Pollock (2009), "Tapping into Juniors' Understanding of E&M: The Colorado Upper-Division Electrostatics (CUE) Diagnostic", *2009 PERC Proceedings*, AIP Press.
- Stephanie V. Chasteen and Steven J. Pollock (2009), "A Research-Based Approach to Assessing Student Learning Issues in Upper-Division Electricity & Magnetism", *2009 PERC Proceedings*, AIP Press.
- Steven J. Pollock and Stephanie V. Chasteen (2009), "Longer term impacts of transformed courses on student conceptual understanding of E&M", *2009 PERC Proceedings*, AIP Press.
- M. Dubson, S. Goldhaber, S. Pollock, and K. Perkins (2009). "Faculty Disagreement about the Teaching of Quantum Mechanics", *2009 PERC Proceedings*, AIP Press.

Steve Goldhaber, Steven Pollock, Mike Dubson, Paul Beale and Katherine Perkins (2009), "Transforming Upper-Division Quantum Mechanics: Learning Goals and Assessment", 2009 PERC Proceedings, AIP Press.

Katherine K. Perkins & Chandra Turpen (2009). "Student Perspectives on Using Clickers in Upper-division Physics Courses", 2009 PERC Proceedings, AIP Press.

S. Chasteen and S. Pollock (2008), "Transforming Upper-Division Electricity and Magnetism", 2008 PERC Proceedings, AIP Press.

## **B. SEI Outreach**

### 1. Departmental structure of the SEI program

Due to an existing need to disseminate the research foundations and pedagogical practices promoted by the SEI, in 2009 Dr. Stephanie Chasteen (STF in Physics) began outreach of SEI materials through workshops, talks, and creation of videos on effective pedagogy, such as clickers. In October, 2009 Dr. Chasteen's appointment was reduced to 50%, of which roughly one-half has been devoted to outreach.

### 2. Specific efforts

#### **a. Video production**

Created a suite of high-quality videos on effective clicker pedagogy housed at <http://STEMclickers.colorado.edu>, and on YouTube at <http://www.youtube.com/user/geekgirl54>. The page at UBC has received approximately 4500 visitors in 2010; approximately 300 hits per month, with an average time on page of 4 minutes. These videos are in the process of being licensed to i>clicker for broader dissemination of effective pedagogical practices to accompany their instructional tool. A series of videos on the PhET interactive simulations was instigated based on the success of this project, for which external funding was obtained.

#### **b. Clicker resource page**

Dr. Chasteen and Sarah Gilbert (at UBC) collaborated to create a website devoted to clickers at <http://STEMclickers.colorado.edu> with a wide variety of useful resources, such as books, the *Instructor's Guide to Effective Use of Classroom Response Systems*, literature references, and videos. This page has been widely advertised and is the top-viewed page on the UBC SEI site, receiving approximately 7500 visitors in 2010; 500-900 hits per month, with an average time on page of 3 minutes.

#### **c. Instructor's Guide**

The *Instructor's Guide* has been reprinted and disseminated at conferences, in departments, talks, and other venues. A total of about 1000 copies have been distributed.

#### **d. Workshops on Effective Clicker Use and Pedagogy**

A series of 1, 2, and 4-hour workshops for instructors on effective clicker use, learning goals, and cognitive science have been designed and facilitated in multiple venues -- “Make Clickers Work for You,” “Writing Great Clicker Questions,” “What Do You Want them to Learn Tomorrow? Writing Learning Goals,” and “What Every Teacher Should Know About Cognitive Research.” Because students also face a lack of preparation for college-level instruction, in part because high school teachers are not always well-versed in the norms of classroom pedagogy at the college level or research-based teaching practice, these workshops were also expanded to include middle- and high-school teachers. Workshops were facilitated mainly by Dr. Chasteen, with assistance or collaboration in many cases from Patricia Loeblein (a high school teacher associated with CU), Dr. Steven Pollock, and Dr. Kathy Perkins. Venues have included the National Science Teachers Association (NSTA; regional and national conferences), local high schools, the American Association of Physics Teachers meetings, the Colorado Science Teachers Conference, the University of Colorado at Denver (Anschutz campus), the University of Colorado at Boulder (Faculty Teaching Excellence Program), International Society for Technology in Education Conference, the Technology in Education Conference, and the Resource Area for Teachers in Denver. A total of about 500 teachers have been impacted by this work.

#### **e. Exhibit Booths at Conferences**

Dr. Chasteen compiled a banner and business card representing the SEI, and a set of handouts and literature reflecting of the work of the SEI (such as the *Instructor's Guide to Effective Use of Classroom Response Systems*, handouts on what education research tells us about effective pedagogy, *Tips for Effective Clicker Use*, *How to Help Students Think Like Experts* etc.). These handouts were distributed at exhibit booths (shared with the PhET project) at a series of professional conferences for faculty and secondary teachers. These were valuable opportunities to share resources and literature relevant to effective pedagogy, and to engage participants in conversation about active engagement and effective use of technology in education. Many teachers had not heard of using clickers with peer instruction, and were interested in the results of education research, which they did not have access to in their daily teaching practice. Over 500 pieces of literature on clickers were distributed, and over 1000 pieces of literature on active engagement strategies. Several hundred business cards, with the [STEMclickers.colorado.edu](http://STEMclickers.colorado.edu) website, were distributed. Conferences attended included the National Science Teachers Association (NSTA; regional and national), American Physical Society, American Chemical Society, and Colorado Science Conference.

#### **f. i>clicker forum**

As a group, the SEI provided expert input to queries from clicker users on i>clicker “forum” website at <http://iclicker.com/forums/>. Approximately 60 responses were given to 35 user questions about various aspects of clickers, such as effective implementation, tips on peer instruction, and technical tips. Each post has been viewed several hundred times. Dr. Chasteen facilitated the assignment of questions to particular STF’s and

faculty members. This consulting relationship has since ended due to lack of use of the forum.

#### **g. Effective communication of PER**

Combining her background in effective science communication and journalism, Dr. Chasteen has been compiling and advocating best practices in communication of Physics Education Research to practicing instructors, in order to improve the impact of such work on instruction at large. She has moderated two guided discussions on the subject at CU-Boulder, and is currently preparing a plenary talk to the PER community in the Pacific Northwest. Through an external grant from the American Association of Physics Teachers, she is creating a small set of audio podcasts (“Learning About Teaching Physics,”) designed to communicate the essential results of PER to practicing teachers, in an engaging and interesting format that demonstrates how that research can directly impact their classroom practice.

### **3. Departmental faculty development and involvement in SEI efforts.**

Workshops were developed with the substantial assistance of Dr. Steven Pollock, Dr. Kathy Perkins and Dr. Michael Dubson. Workshops were conducted with the assistance of Dr. Steven Pollock, Kathy Perkins, and Jenny Knight (MCDB). Dr. Pollock, along with Dr. Chasteen used Dr. Chasteen’s materials for a campus-wide Faculty Teaching Excellence Program workshop on clickers, improving their own pedagogical expertise in teaching faculty about effective pedagogical practices. Faculty and postdocs at CU and other institutions have used the clicker workshop materials developed through the SEI, and Dr. Chasteen has used those materials to develop workshops for i>clicker and at other institutions, reaching a broad audience of faculty. Based on her experience, Dr. Chasteen also developed a workshop for faculty development professionals, about best practices helping faculty use clickers.

Videos included interviews with 10 SEI faculty, providing those faculty with a valuable opportunity to share their expertise with a broader audience.

Dr.’s Kathy Perkins (Physics), Noah Finkelstein (Physics), Mike Klymkowski (MCDB), Seth Hornstein (Astronomy and Astrophysics), Steven Pollock (Physics), Valerie Sloan (Geology), Margaret Asirvatham (Chemistry), Doug Duncan (Astronomy and Astrophysics) and Jennifer Knight (MCDB) all contributed answers to the i>clicker Q&A forum. This provided valuable experience in translating their pedagogical knowledge to instructors outside of CU.

The outreach efforts primarily affect the faculty and secondary teachers at a variety of institutions. Among the 100 participants who completed our surveys regarding their experiences in workshops on clickers and education research, 93% indicated that they were “likely” or “very likely” to use the ideas presented in the workshop, and 88% indicated that they were “likely” or “very likely” to pass the ideas on to a colleague. The vast majority indicated that they were “very likely.” It is notable that within the clicker workshops, 60% of participants had not yet used clickers – thus, these outreach efforts have a substantial possibility of affecting the pedagogical strategies of new clicker users.

Participants in the NSTA workshops (which have a separate feedback form) indicated that the sessions met their needs (“strongly agree”) and recommended that the session be repeated at future conferences (split between “agree” and “strongly agree”).

#### 4. Goals for 2011

Continue to provide workshops on effective clicker and other pedagogical techniques to those who request it. Currently, a Faculty Teaching Excellence Program workshop on learning goals is planned for March 2011. Individual departments may be contacted for their interest in a department-specific workshop.

Create “template” workshops on clickers, learning goals, and other topics, which may be used by faculty development professionals.

We may create “virtual” workshops based on our materials, with video, worksheets, and online activities to engage participants.

Potential future videos include Preparation for Future Learning Activities, Learning Goals, Effective Questioning, Running a TA Meeting, Interactive Lecture Demos, and Just In Time Teaching.

Disseminate and advertise videos widely, and promote YouTube and STEMclicker.colorado.edu websites in the education and science communities.

Write relevant white papers for informal dissemination, such as the use of whiteboards in college settings, and running homework help sessions. Potentially publish an article in an education-oriented journal, such as *The Physics Teacher*, on relevant pedagogical strategies. Contribute or improve upon articles in Wikipedia on education research topics.

## IV. SEI in Chemistry

### A. Departmental structure of SEI program

#### 1. People:

Faculty Director: Professor Robert Parson.

Science Teaching Fellow: Dr. Laurie Langdon (half time since August 2010)

Graduate Student: Ms. Marta Maron

#### 2. Departmental structures / decisions

Overall departmental administration is provided by the Chair, Professor Bruce Eaton (Jul 2009-present), and the Executive Committee, Professors Tad Koch, Veronica Bierbaum, James Goodrich, and David Walba). The Undergraduate Curriculum Committee (Professors Parson, Bierbaum, Robin Knight, and Joel Eaves, plus Senior Instructors Margaret Asirvatham and Susan Hendrickson) is responsible

for overall supervision of the undergraduate program. The General Chemistry Coordinating Committee (Professors Bierbaum, Parson, James T. Hynes, Thomas Cech, Daniel Feldheim, and Drs. Hendrickson and Asirvatham) deals with issues specific to the large general chemistry courses. Senior Instructor Dr. Margaret Asirvatham is Director of the General Chemistry Program. These are all standing committees of the department.

## **B. Course-related efforts**

During 2010, SEI Chemistry was primarily involved with creating a new lower division course, General Chemistry II for Majors (Chem 1271). Involvement with the regular General Chemistry sequence and with upper division Physical Chemistry continued, but at a lower level than in previous years.

### **1. *General Chemistry 1 (CHEM 1113) and General Chemistry Lab 1 (CHEM 1114)***

#### **a. Background**

Chem 1113 is the standard beginning chemistry course for science majors and premedical students. With more than 1200 students per year it is the largest course in the department. Prior to 2010 lecture and laboratory were combined into a single 5-credit course, Chem 1111, but now lecture (Chem 1113) and lab (1114) courses are separate though a strict corequisite is imposed.

#### **b. Description of ongoing activities**

Chem 1113/1114 and its successor, Chem 1133/1134 were the primary target of SEI activities during the first few years of the project. These activities have been described in previous years' reports. No major changes were made in 2010, although data continued to be collected.

##### **i. Learning Assessment: instruments and findings**

The CLASS survey of student attitudes, which has been administered to General Chemistry students since 2004, has revealed that students do not view chemical problems the way that experts do, by constructing atomic and molecular representations, and that this disparity becomes worse after instruction – in other words, the effect of the course is to make the students think less like a chemist. Over the past three years, the overall negative shift in attitudes has not gone away, but the negative shift in the “chemical thinking” category has diminished (and in some cases become positive.) A concept survey, based upon validated literature sources, has been administered since Fall 2006. Learning gains, as measured by this survey, increased from ~15-20% in 2006-2007 to ~30% in 2008 and have held steady since then.

##### **ii. Changes in course instruction: no major changes were made in 2010.**

#### **c. TA training.**

The TA training program established two years ago was revised on the basis of observations during last year's implementation. As in 2008-2009, it was given to all entering graduate students. Hannah Robus, the Laboratory Coordinator for Chem 1113, has taken over responsibility for the training.

## **2. *General Chemistry 2 (CHEM 1131) and General Chemistry 2 Lab (CHEM 1134)***

### **a. Background**

This is the successor to CHEM 1113/14. It is taken by approximately 800 students per year; students must pass CHEM 1113 with a grade of C- or better in order to register for CHEM 1133. The course covers a smaller number of topics in greater depth than is the case for CHEM 1111. Many of the general issues, as well as specific items (such as the CLASS survey) discussed above concerning CHEM 1113 apply to CHEM 1131 as well, and will not be repeated here.

### **b. Description of ongoing activities**

- i. Learning Assessment: CLASS and Concept Surveys were given again in 2010. The results are similar to previous years. Graduate student Marta Maron continued a project of systematic observations of student work and discourse in the laboratory that she began in 2009. Ms. Maron was in part supported by the SEI for this work.
- ii. Changes in Course Instruction: no major changes were made in 2010.

## **3. *Introductory Chemistry (CHEM 1021)***

This course is taken primarily by students who need additional instruction in basic chemistry before taking Chem 1111. In Summer 2009, Dr. Christine Kelley, with help from Drs. Hendrickson and Langdon, initiated a major transformation of this course. A major component of the transformation was the introduction of student-centered recitation activities, analogous to those created earlier for Chem 1113. This new structure was retained in 2010. In Spring 2010, the faculty and graduate TA's involved in the course collaborated with the PhET project to introduce a newly created simulation into the recitation.

## **4. *General Chemistry 1 for Majors (CHEM 1251)***

### **a. Background**

In 2008, the Department decided to create a new General Chemistry Sequence for Chemistry and Biochemistry majors. Professor Thomas Cech taught the course for the first time in Fall 2009, and for the second time in Fall 2010. Dr. Langdon worked with Dr. Cech on both occasions. Approximately 100 students took the course in each term.

### **b. Description of ongoing activities**

- i. Learning goals

In Fall 2009, Professor Cech had developed a set of "big ideas" to serve as unifying elements for the course, and designed four "Career Scenarios" to demonstrate how the concepts discussed in class could arise in real-world situations. In Fall 2010 Dr. Langdon worked on expanding these very high-level goals into a more detailed set.

ii. Learning Assessment: instruments and findings

Both CLASS and Concept Surveys were administered to Chem 1251 students before and after instruction. The CLASS results displayed the usual negative shift, although significantly smaller than in Chem 1113. The concept survey data have not yet been analyzed in detail, although it appears that as in the previous year, the learning gains are larger than in the nonmajors' course (37% vs. 30%).

iii. Changes in course instruction

No major changes were made in Fall 2010, although the materials developed in Fall 2009 (clicker questions, interactive lecture demonstrations, and student small-group activities in lecture and in recitation) were further refined.

**5. *General Chemistry 2 for Majors (CHEM 1271)***

a. Background

This is the successor course to Chem 1251. It was taught for the first time in Spring 2010. The instructor was Professor Daniel Feldheim. This course was the primary locus of SEI activity in 2010.

b. Description of ongoing activities

i. Learning goals

Professor Feldheim followed Professor Cech's example by designing large-scale "big ideas" and associated career scenarios.

ii. Learning Assessment: instruments and findings

Both CLASS and Concept Surveys were administered to Chem 1251 students before and after instruction. The results are similar to Chem 1251: somewhat better performance than in the nonmajors' course.

iii. Changes in course instruction

The lecture course was transformed following the template used in Chem 1251: clicker questions were used throughout, with students assigned to permanent "clicker groups" throughout the term. Professor Feldheim went to considerable length to tie the material in to modern applications.

**6. *Physical Chemistry with Biological applications (CHEM 4411)***

a. Background

In prior years SEI was involved in two upper division courses, Chem 4511 (Physical Chemistry I) and Chem 4411 (Physical Chemistry I with Biological Applications). These two classes cover similar material (primarily chemical thermodynamics and applications) with different emphases. After summer 2009, SEI personnel were no longer directly involved in course transformation, but the faculty teaching the courses continued to refine their activities.

b. Description of ongoing activities

i. Assessment

The concept survey developed Professor Parson, Professor Amy Palmer, and Science Teaching Fellow Thomas Pentecost in summer of 2008 was again administered to Chem 4411 students in Fall 2010. The results have not yet been analyzed.

ii. Changes in course instruction

In prior years Professor Amy Palmer had developed a suite of in-class small group activities. While these were well received, Palmer noted that they were difficult to administer when only two facilitators (the instructor and a graduate TA) were present. In Fall 2010, therefore, Professor Palmer added three undergraduate learning assistants to the class. She also used clicker questions for the first time in Fall 2010.

### C. Departmental faculty development and involvement in SEI efforts

A principal goal for 2010 was to ensure that changes catalyzed by the SEI could be made sustainable by associating them with existing departmental structures. Significant progress was made in two areas: the TA training program, originally developed by STFs Langdon and Pentecost, is now administered by the General Chemistry Program through one of the general chemistry laboratory coordinators (Hannah Robus), and the LA application and selection process has been transferred from Dr. Langdon to the Undergraduate Curriculum Committee (Robert Parson, Chair.)

### D. Presentations and Papers

One paper:

"TA training that integrates Pedagogy and Content", by Thomas C. Pentecost, Laurie S. Langdon, Hannah K. Robus, Margaret Asirvatham, and Robert Parson, is going through final revisions, and submission to the *Journal of College Science Teaching* is expected by 15 March 2011.

Two more papers, dealing with the Learning Assistant Program and the Physical Chemistry course transformation, are partially written.

Four SEI-related presentations were given at the 21st Biennial Conference on Chemistry Education in August 2010:

Laurie Langdon, "Future teachers' contributions to research, improve, and sustain a student-centered recitation model at the University of Colorado"

Hannah Robus, "Training first year general chemistry teaching assistants for success"

Susan Hendrickson and Laurie Langdon, "Utilizing message boards for online help in large enrollment classes"

Robert Parson, "Interactive engagement strategies for undergraduate physical chemistry"

## **E. Goals for 2011**

1. Archive materials developed in previous years.
2. Write up and submit results of research for publication.

## **V. SEI in Geosciences**

### **A. Background**

Participation in the Science Education Initiative (SEI) in the Department of Geological Sciences (GEOL) is entering its 5th and final academic year. The program has become an integral part of the teaching mission of the department and the faculty acknowledges that it has had a very positive impact on the culture of teaching. Faculty now commonly having conversations about teaching and effective means of student learning.

Since it was established, Prof. David A. Budd has served to (i) coordinate efforts of the SEI within GEOL and report to the departmental unit; (ii) act as faculty liaison to the SEI; (iii) supervise the postdoctoral Science Teaching Fellows (STFs) who spearhead the implementation of SEI's goals to improve science teaching to our entire undergraduate curriculum as well as conduct research in science education strategies; and (iv) serve on the SEI Advisory Board.

### **B. Human Resources**

In 2010, we had three postdoctoral STFs present in the department during the spring term and two present in the summer and fall. The three STFS in the spring and early summer were Dr. Andrea Bair, Dr. Michael Vredevoogd, and Dr. Leilani Arthurs. Dr. Arthur's left in mid-year to take an Assistant Professor position at South Georgia State University. With just one year left in the SEI program, and the fact that new Geoscience STFs have taken at least a year to become effective, the decision was made to conserve resources and not hire a new, 3rd STF. The savings realized were returned to SEI central for redistribution to other units..

### **C. Implementation Strategy and Overview of Achievements**

The SEI-GEOL has pursued a multi-pronged approach to implement new pedagogical techniques in our undergraduate curriculum. Focus was on introductory-level core curriculum courses during the first two years of the program. These 1000 and 2000-level courses generate some 8000 student credit hours per year, and nearly half of our 30 tenure-track faculty teach one of these courses in any one year. The faculty teaching these courses agreed upon overarching, course-level learning goals; most developed their own set of

lecture-level learning goals; all implemented some classroom teaching strategies that incorporate varying amounts of student-student and student-teacher interactive strategies and formative assessments (e.g., clickers and in-class activities); and we initiated the development of pre and post instruction concept inventories (subsequently completed for GEOL 1010 and 2100).

Beginning in year 3 (2008-2009 AY) and extending into year 4 (Fall of 2009-2010 AY), Geol-SEI began implementation of the SEI in our major-track and non-major 3000-level courses. The initial efforts were in Oceanography (3070), the laboratory components of Mineralogy (3010) and Structural Geology (3120), and a new course in Fluid Earth (3820). These efforts were completed, and new efforts were undertaken in 2010 for Global Change, the Geologic Perspective (3040), Sedimentology and Stratigraphy (3430) and the laboratory component of Paleobiology (3410). In addition, we began to test new ideas in the introductory courses.

As noted in prior annual reports, the STFs have become deeply embedded and highly utilized resource in the Department of Geological Sciences. Most faculty are now very aware of the successes of the program and comfortable with the support provided by the Teaching Fellows. Our faculty-STF collaborative in the SEI will have positive repercussions for many years to come. It has taken many of our faculty out of their comfort zone and exposed them to fresh new ideas about how to teach geology to our undergraduate students. Some are now forging out on their own, implementing transformations to their teaching in other courses (upper division undergraduate and graduate courses) with only minimal input and guidance from the STFs.

## **D. Course Curriculum Outcomes**

### **1. *Introductory Courses***

#### **a. *Introduction to Geology (GEOL 1010)***

- Eleven different instructors teach this course, with three to five of them teaching it in any particular semester. In prior years, this cohort of faculty had worked with STF Andera Bair to develop course-level learning goals, implement clicker technologies, and develop a suite of xxx in-class activities that develop students' conceptual understanding and scientific skills with respect to various topics (e.g., earthquakes, groundwater, etc) that were being used by most instructors.

- In 2010, STF Mike Vredvoogd worked with Dr. Kevin Mahon to develop two new in-class activities covering volcanic eruptions and the use of seismic waves to understand anisotropy deep within the Earth.

- In a summer school session of GEOL 1010, STF Vredvoogd experimented with 'pyramid' exams, where students would complete the exam, and then retake it in a group. The group retake emphasizes student-student discussion designed to force students to explore and discuss their reasoning about the exam questions they had initially selected different answers. Student feedback positive, both in terms of using the exams to improve learning (intrinsic values), and in terms of an opportunity to improve scores (extrinsic motivations).

#### **b. *Historical Geology (GEOL 1020)***

- Five different instructors teach this course, with at least three of them teaching it in any academic year. In prior years, this cohort of faculty had worked with STF Jenifer Stempien to develop course- and topic-level learning goals, implement clicker technologies, expand homeworks, and align summative assessments with learning goals. They also agreed to restructure the content of the lecture material so as to focus case studies as examples of key concepts instead of trying to cover all of geologic time. All five instructors had worked, to varying degrees, with STF Stempien in 2007, 2008, or 2009 to implement these changes.

- In fall 2010, Professor David Budd, with the assistance of STF Mike Vredvoogd, developed a series of 10 in-class activities that aligned with learning goals and were intended to have students develop their knowledge through a constructivist approach. Examples of activities include use of fossils to define relative time and correlate rocks from different areas, use of stable isotopes to analyze ancient climates, reconstruction of paleogeography from the spatial distributions of different rock types. The activities were implemented in a 48-person class by breaking the students up into three “Friday recitations”, each supervised by an undergrad learning assistant.

- The effectiveness of the activities relative to the delivery of the same content in more traditional lectures was assessed by using the activities in a section of 48 students, while delivering the same material via lecture and concept clickers to a 160 student lecture section also taught by Dr. Budd. STF Vredvoogd interviewed students and tracked homework and exam performance to assess the effectiveness of the activities vs. the control group in a large lecture setting. With the exception of a few concepts (about 1/3<sup>rd</sup> of the activities) the preliminary results suggest little discernable differences in learning occurred, but significant differences in students’ affect (attitudes and motivation) did develop.

- A report on this experiment will be delivered to the Departmental faculty for their consideration as members of the 1020 teaching cohort would like to further experiment with this “Friday recitation” option in lieu of a 3<sup>rd</sup> lecture period.

***c. Introductory Geology Laboratory (GEOL 1030)***

- GEOL 1030 is a stand alone, 1 credit-hour laboratory course designed for the 1-credit hour science lab requirement in the A&S core curriculum. It is not linked to any specific course, although it compliments GEOL 1010. Each section of the course is taught by a graduate teaching assistant under the overall supervision of Senior Instructor Lon Abbott.

- STF Arthurs advised and assisted Dr. Abbott on the development and writing of the first half of a new lab manual for the course (Abbott completed the manual after Arthurs departed CU). The concept survey for the course, initiated in 2009 by Arthurs was completed in the summer of 2010 by Budd and administered for first time in fall 2010. The survey results showed which pre-instruction misconceptions were eradicated by instruction, and which (one) persisted in spite of

deliberate instructional efforts. The survey also identified a few concepts that were not learned well by students, and adjustments to instructional approaches are being implemented by Dr. Abbott in the spring of 2011.

## 2. *Upper-Division Courses*

### a. *Global Change: the Geologic Perspective (GEOL 3040)*

- STF Arthurs taught this course in spring 2010 as its regular instructor. She implemented a full SEI transformation of the course, including (1) articulation of learning goals, (2) alignment of the lectures and assessments with those learning goals, (3) introduction of reading quizzes, homework, large and small group discussions, interactive in-class activities, and a capstone team projects involving research, analysis, and presentation.

- All materials prepared by Arthurs were archived on the SEI web site and have been made available to all subsequent instructors of this course.

### b. *Paleobiology (GEOL 3410)*

- STF Dr. Andrea Bair assisted Professor Dean Smith in 2009 and Professor Jaelyn Eberle in 2010 in the effort to transform aspects of this majors-track course. In 2009, STF Bair determined the major roadblocks to student learning in the course and the 2010 efforts were focused on overcoming these issues. During the course of the two semesters of effort: (1) a complete set of lab and lecture learning goals were developed, and (2) twelve new laboratory exercises were developed, each closely aligned with the concepts introduced in lecture, and each designed to provide students with opportunities to actively work with, or apply, fundamental concepts.

- Lab exercises now include a warm-up portion and students working in collaborative learning groups, both strategies which we found to work well in 2008 and 2009 when transforming other upper-level laboratory courses. Applications and contexts of primary interest or utility for geologists were made explicit and the focus of at least a portion of each exercise. Primarily biological applications (e.g., how the fossil record contributes to our understanding of evolution) were also included.

- Particular attention was also paid to developing student understanding and use of phylogenetic or evolutionary trees, and a combined lecture-lab module was developed based on current research on teaching and learning of this subject in undergraduate biology courses. Assessing student learning of this concept became a small research project during the semester.

- SEI Graduate Research Assistant Alex Dutchak observed all laboratory sessions, conducted student interviews, and assessed student thinking and affect through surveys.

- Analysis of student interviews and surveys is nearing completion. Pertinent results to date indicate that students had a primarily positive experience in the course, but that our reforms were not entirely effective in supporting students' viewing the lab and lecture components as well-connected. We provisionally conclude that restricting all instruction and assessment of areas related to fossil organisms themselves (as opposed to concepts in Paleobiology) to the laboratory component is a

very difficult constraint to work within while supporting student learning and understanding of why they are asked to work with the fossils in lab.

***c. Sedimentology and Stratigraphy (GEOL 3430)***

- Professor Mary Kraus and STF Bair collaborated on major and sweeping reforms of this course, including developing a complete set of learning goals for lecture and lab exercises.
- Development of new instructional and assessment materials for lecture component, also targeting student learning difficulties (including homework exercises and in-class materials)
- Determined, through observations and informal discussions with students and faculty, that clickers were not significantly improving the interactivity of lecture, so abandoned their use.
- Modified lab exercises to 1) adopt a more interactive engagement approach by the TA, 2) incorporate information on student conceptual and skill difficulties, 3) align activities with course goals and priorities, 4) incorporate strategies successful in prior geology lab reforms (e.g., warm-up activities, scaffolding, and learning groups). Efficacy of the new exercises was assessed by classroom observation, formal and informal interviews with students, examination of student work, and student surveys. Learning groups were highly interactive and effective in the lab, and students in the groups reported working together on homework and studying outside of class.
- A list of student learning difficulties and misconceptions was compiled for the instructor based on classroom observations, examination of student work, and informal and formal student interviews.
- Homework assignments were modified in order to align them with learning goals and student conceptual and skill difficulties. Formal and informal student interviews, surveys, and examination of student work informed the revisions.
- Student background and ability with several critical skills (including scientific explanation, working with spreadsheets, distinguishing data from interpretations, and drawing and interpreting sketches) were investigated and recommendations for future versions of this course were made. Short tutorials for spreadsheet work and the concept of contouring were specifically developed.
- It also became apparent, through classroom observations, that many students were not including chalkboard drawings in their notes, despite the fact that Professor Kraus considered these sketches critically important. Considerable energy was put into getting students to draw the sketches, and to use those drawings to monitor of their own understanding of concepts. We developed more explicit note-taking recommendations, explained reasoning, and developed visual organizers and assessments for students.
- It became apparent early in the course that students' written answers on assessments were incomplete, and this was a major frustration for the instructor. Efforts were made to determine if the issue was students' ability to clearly articulate their understanding in writing and/or their incorrect thinking and understanding. We identified a curriculum for teaching scientific writing from the literature and implemented it midway through the class, but no significant improvement occurred.

Bair analyzed survey questions and informal and formal interviews with students in which they answered conceptual questions and were queried on their approaches or strategies for answering questions. Key outcomes of this analysis were:

1. Students who scored high both on their course assignments and on interview questions (using a scoring rubric) had substantial prior writing experience AND saw their experience as highly pertinent to writing for this course. These students also generally expressed that their responses needed to explicitly address the question (and all its parts), and they needed to carefully and completely communicate their understanding to the instructor when answering the question.

2. Students interviewed who scored lower on course assignments and interview questions did not have substantial prior experience with writing, did not see their experience as pertinent, and/or viewed their task in answering questions differently. Lower scoring students usually expressed that the instructor would or should know what their answer meant, and that their task was to provide a short phrase or answer that the instructor would recognize as reflecting student understanding (that is, they did not need to completely justify or connect their responses, because the instructor was an expert and therefore could make the connections without the student making them explicit). Such students also tended to give an example without connecting it to their reasoning, or simply giving an example and not actually answering the question in their own words (without articulating their reasoning).

#### **E. Other Accomplishments**

In prior years, the GEOL-SEI had already

- Facilitated iClicker support and training for all departmental faculty (clickers are now widely used independent of SEI assistance),
- Implemented a Tutoring and Study Room (T&SR) for geology majors (now operated by the Department independent of the SEI)
- Developed and presented a teaching assistant summer training workshop (still done by GEOL-SEI, but a plan to continue the effort in future years independent of the SEI has been developed)
- Assisted with the implementation of peer learning assistants in select courses.

In 2010, an undergraduate assistant, working in cooperation with Dr. Budd, completed the archiving on the SEI web site of all course materials developed over the last four years. Materials for **nine** (and growing) courses are now available for all faculty to access in an easily scanned format. This archive, in terms of number of courses and amount of material is the largest for any of the departments participating in the SEI initiative.

#### **F. Faculty participants in SEI activities:**

There are 29 faculty and one senior instructor in Geological Sciences, and 2/3rds of them have now interacted with the SEI to some degree. In 2010, the faculty engaged with STFs on a significant level (designing, implementing, and/or evaluating various SEI objectives and/or approaches) were:

- David Budd
- Mary Kraus
- Lon Abbott

- Jaelyn Eberle
- Karen Chin
- Kevin Mahon
- Gifford Miller

## G. Goals for 2011

The SEI project in Geological Sciences will end on July 1, 2011. Overall goals for the final six months of effort are thus focused on (1) completion of efforts in progress, and (2) final documentation of all reforms undertaken.

1. Final class reform efforts will focus on:
  - **Introductory Geology Laboratory** (GEOL 1030) - Interviewing of the teaching assistants to assess their insight what is working as planned, what is not, difficulties and misconceptions, and misalignments.
  - **Introductory Geology Laboratory** (GEOL 1030) – Final testing of the concept inventory.
  - **Sedimentology and Stratigraphy** (Geol 3430) – work with Professor Kraus and revisit issues identified in 2010 regarding writing and numeracy components of the course.
  - **Introduction to Geology** (GEOL 1010) – Develop pre-instruction exploratory activities for use at the beginning of each major unit.
  - **Historical Geology** (GEOL 1020) – reformat in-class learning activities to homework assignments, thus giving faculty more flexibility in how they implement these learning activities.
  
2. Documentation of revisions, supporting pedagogy, and/or outcomes of STF observations and students surveys were be collected in reports and/or manuals for:
  - **Introduction to Geology** (GEOL 1010) – update the list of student learning difficulties for dissemination to all faculty.
  - **Historical Geology** (GEOL 1020) - Prepare a report on the fall 2010 recitation activities, including results from observations & interviews (pre and/or post), learning difficulties and misconceptions, revised copies of each activity, and alternative versions that other instructor’s might prefer given slight variations in instructors’ content.
  - **Structural Geology** (GEOL 3120), **Mineralogy** (GEOL 3010), and **Paleobiology** (GEOL 3410) – write “implementation guides” for the laboratory revisions associated with each course. Document the goals of each lab, the pedagogical reasoning behind lab organization, the reasoning behind lab handouts and questions, and advice on how to effectively lead the labs. Intended audience is future TAs of the courses.
  - **Paleobiology** (GEOL 3410) and **Sedimentology and Stratigraphy** (Geol 3430) – prepare summary reports that document (1) transformations accomplished (learning goals defined; lab revisions made; new activities developed; suggestions for quizzes; homework and exams; survey’s developed and results from those surveys; summation of student interview results) and (2) lab reforms and lab-lecture alignments.
  - **Fluid Earth** (GEOL 3280) – report documenting examples of improved classroom tools (e.g., revised homework, discussion guides, etc).

## H. STF Professional Development

- Supporting their presentations of papers at the annual Geological Society of America and/or American Geophysical Union meetings
- Paying for their participation in professional workshops on pedagogy at the same meetings
- Facilitating and encouraging their development of SEI-related research
- Supporting their efforts to publish in a timely manner results of completed research.

#### **I. Presentations at National Meetings**

S. Palladino and **L. Arthurs**, 2010, Under-representation of Anthropogenic Erosion in Visions of a Sustainable Future: Geological Society of America, Abstracts with Program, v. 72 (5).

**Bair, A.** How clicker technology affects students' voting behavior and attitudes. Geological Society of America Abstracts with Programs. 72(5):555.

**Vredevoogd, M.,** and **Bair, A.R.** Translating research on how people learn to the geoscience classroom. Geological Society of America Abstracts with Programs. 72(5):588.

#### **J. Research Papers**

**Arthurs, L.**, 2011, What college-level students think: Student cognitive models of geoscience concepts, their alternate conceptions, and their learning difficulties: GSA Special Papers: Qualitative Inquiry in Geoscience Education Research.

**Arthurs L.,** and T. Marchitto, 2011, A qualitative methods approach to developing an introductory oceanography concept inventory survey: GSA Special Papers: Qualitative Inquiry in Geoscience Education Research.

**Bair, A.R.,** in press, How 'clicker' technology affects students' voting behavior and attitudes: Journal of Computers in Mathematics and Science Teaching.

Duncan, D., and **L. Arthurs**, accepted with revisions, How do students respond to simple ways of improving student attitudes about science?: Astronomy Education Review.

## **VI. SEI in Integrative Physiology**

### **A. Departmental structure of SEI program**

1. People
  - a. Faculty Director: Bill Byrnes (August 2008-present)
  - b. STFs: Francoise Bentley, Teresa Foley, Ph.D., Katharine Semsar, Ph.D. (10%)
2. Departmental structures
  - a. A Teaching Committee oversees the organization of courses in the department. In addition, the Teaching Committee makes decisions on learning goals, additional recitation sections, and changes to course structure as suggested by the SEI.

- b. Since the department has been involved with the SEI, the IPHY department has been working to restructure the degree requirements for the undergraduate major.
- c. This year our focus has been to continue faculty development through working groups and to continue upper-division course development and sustainability. We have six upper-division core courses, which students must take at least three to graduate. Another focus has been to educate faculty on the use and implementation of thought questions, a new type of clicker question, introduced by an STF and an IPHY faculty member.

## **B. Course-related efforts**

### **1. *Undergraduate Statistics (IPHY 2800) and Graduate Statistics (IPHY 5800)***

- a. **SEI role in this course: Active involvement**
- b. **Faculty involved: Marissa Ehringer, Ph.D. (IPHY 2800, Spring), Steven Hobbs, Ph.D. (IPHY 2800, Spring), Matt McQueen, Ph.D. (IPHY 5800, Fall), Monique LeBourgeois, Ph.D. (IPHY 2800, Fall & Spring), Kenneth Wright, Ph.D. (Statistics Committee Chair)**
- c. **STFs involved: Kate Semsar & Teresa Foley**
- d. **TA support: Yes, two for IPHY 2800 and one for IPHY 5800.**
- e. **IPHY 2800 serviced 292 undergraduate students in 2010.**
- f. **IPHY 5800 serviced 24 graduate students in 2010.**
- g. **Current Status**
  - i. The STFs and faculty developed a final learning goal document for both courses.

### **2. *Introduction to Human Anatomy (IPHY 3410)***

- a. **SEI role in this course: Moved from active involvement to consultants**
- b. **Faculty involved: Christopher Lowry, Ph.D (Spring), Ruth Heisler, M.S. (Fall), Leif Saul, Ph.D. (Fall)**
- c. **STFs involved: Kate Semsar**
- d. **TA support: A full time TA has now been appointed to this course for assistance with homework and student office hours.**
- e. **IPHY 3410 serviced 671 undergraduate students in 2010.**
- f. **Current Status**
  - i. Faculty continue to use learning goals, clickers, weekly homework assignments, pre-post tool, and the biology CLASS.
- g. **Assessment tool**

- i. The assessment tool for this course has been finalized and is called the ALI, Anatomy Learning Inventory. This focuses on student misconceptions and difficulties. Kate Semsar is currently writing up the ALI for publication.

**h. Sustainable resources for faculty**

- i. An electronic binder was developed and is to be used as a tool for current and future instructors. This binder includes: primary physiology education literature, learning goals, clicker questions, common student misconceptions, knowledge level of students entering the course, potential questions for future homework sets, pre/post assessment tool, and exam questions. This binder has now been passed on to faculty and they have agreed to have a lead Anatomy faculty member who coordinates future sharing of materials.

**3. *Human Physiology I (IPHY 3480)***

**a. SEI role in this course: Active involvement**

**b. Faculty involved: Kenneth Wright, Ph.D. (Fall), Janet Casagrand, Ph.D. (Spring), and Steven Hobbs (Fall)**

**c. STFs involved: Franny Bentley**

**d. TA support: Yes, two for each semester. In addition, six undergraduate learning assistants have been added for the spring semester.**

**e. IPHY 3470 serviced a total of 406 undergraduate students in 2010.**

**f. Current Status**

- i. Faculty continue to use learning goals, clickers, homework assignments, pre-post tool, and actively share materials among one another. This year faculty added the use of thought questions and in-class worksheets.

**g. Assessment tool**

- i. This course has an assessment tool that is actively being used by faculty. This tool has been able to document increases in learning in various concepts. Most notably, students have shown increases in understanding the role of ligands and receptors in intracellular signaling.

**h. Faculty resources**

- i. An archive has been created and will be distributed to the faculty. Using this archive, faculty will share their new resources between one another each year.

**4. *Human Physiology II (IPHY 3480)***

**a. SEI role in this course: Active involvement**

**b. Faculty involved: William Byrnes, Ph.D. (Spring), Heidi Bustamante, M.S. (Fall)**

**c. STFs involved: Teresa Foley**

**d. TA support: Yes, two each semester.**

**e. IPHY 3480 serviced a total of 395 undergraduate students in 2010.**

- f. Current status**
    - i. A final working draft of learning goals for this course has been reached. This year, faculty added the use of thought questions.
  - g. Assessment tool**
    - i. Faculty are currently working with the STF to develop an assessment tool for this course.
  - h. Understanding student thinking and misconceptions**
    - i. In order to help understand student thinking, the STF has been documenting student questions and responses to oral questions and in class activities (primarily concept maps) during class time.
  - i. Class activities**
    - i. Clicker, homework (fall semester), surveys, and class projects (spring semester) continue to be used.
    - ii. To ensure consistency in course materials, faculty have worked with the STF to align their exam questions against the learning goal document.
- 5. *Cell Physiology (IPHY 3060)***
- a. SEI role in this course: Active involvement**
  - b. Faculty involved: David Allen, Ph.D. (Fall), Robert Hermanson, Ph.D. (Lab Coordinator)**
  - c. STFs involved: Franny Bentley and Teresa Foley**
  - d. TA support: Yes, three for the fall semester.**
  - e. IPHY 3060 serviced a total of 73 undergraduate students in 2010.**
  - f. Current Status**
    - i. Learning goals were finalized and aligned with course quizzes and exams.
  - g. Understanding student thinking and misconceptions**
    - i. In order to help understand student thinking, the STFs have been documenting student questions and responses to oral questions during class time. This document has been summarized and provided to the faculty throughout the semester.
- 6. *Neurophysiology (IPHY 4720)***
- a. SEI role in this course: Active involvement**
  - b. Faculty involved: Roger Enoka, Ph.D. (Spring), Janet Casagrand, Ph.D. (Fall)**
  - c. STFs involved: Franny Bentley**
  - d. TA support: Yes, four each semester.**
  - e. IPHY 4720 serviced a total of 149 undergraduate students in 2010.**

**f. Current Status**

- i. A final draft of goals was reached. One faculty member uses this document in their course and aligns exams, homework and clicker questions with the goals. The other faculty member uses this document to structure the course.

**g. Class activities:**

- i. Help Room, clicker questions, homework assignments continue to be used. This year thought questions and case studies were added to increase engagement and real world application in the course.

**7. Endocrinology (IPHY 4440)**

**a. SEI role in this course: Active involvement**

**b. Faculty involved: Pei-San Tsai, Ph.D. (Spring), David Norris, Ph.D. (Fall)**

**c. STFs involved: Teresa Foley**

**d. TA support: Yes, two each semester.**

**e. IPHY 4720 serviced a total of 220 undergraduate students in 2010.**

**f. Current Status**

- i. A final version of the goals was reached. This document has been aligned with the course recitation activities and exams. This year faculty added the use of thought questions.

**g. Assessment Tool**

- i. Faculty worked with the STF to develop an assessment tool for this course. It was piloted in the fall and was given in its final form in the spring.

**h. Understanding student thinking and misconceptions**

- i. In order to help understand student thinking, the STF has been documenting student questions and responses to oral questions and in class activities during class time.

**i. Recitations**

- i. Recitations have been modified to align with the course goals. Activities included concept maps, strip sequences, and worksheets that focus on the learning goals of the course.

**8. Immunology (IPHY 4600)**

**a. SEI role in this course: Active involvement**

**b. Faculty involved: Monika Fleshner, Ph.D. (Spring), Teresa Foley, Ph.D. (Summer)**

**c. STFs involved: Teresa Foley**

**d. TA support: Yes, two each semester.**

**e. IPHY 4600 serviced a total of 200 undergraduate students in 2010.**

**f. Current Status**

- i. A final draft of the course learning goals has been established by the STF and will be tested in the spring with the second faculty member. This year faculty added the use of thought questions.

**g. Understanding student thinking and misconceptions**

- i. Faculty worked with the STF to develop an assessment tool for this course. It was piloted in the fall and was given in its final form in the spring.

**h. Understanding student thinking and misconceptions**

- i. In order to help understand student thinking, the STF has been documenting student questions and responses to oral questions and in class activities during class time.

**i. Recitations**

- i. Recitations have been modified to align with the course goals. Activities included concept maps, strip sequences, and worksheets.

**9. Biomechanics (IPHY 4540)**

**a. SEI role in this course: Consultants**

**b. Faculty involved: Alaa Ahmed, Ph.D. (Spring)**

**c. STFs involved: Franny Bentley**

**d. IPHY 4540 serviced a total of 58 students in the spring.**

**e. Current Status**

- i. The faculty member desired to add clicker questions to increase engagement in their course. The STF occasionally observed the course to provide feedback, which involved the addition of clickers to the class.

**10. Human Physiology Laboratory (IPHY 3435)**

**a. SEI role in this course: Active involvement**

**b. Faculty involved: Heidi Bustamante, M.S. (Committee Chair), Janet Casagrand, Ph.D. (Committee member), Robert Hermanson, Ph.D. (Lab Coordinator)**

**c. STFs involved: Franny Bentley**

**d. Current Status**

- i. Faculty and the STF are actively involved in reforming the laboratory using an inquiry-based approach. This laboratory will have both a human and comparative approach to serve the Human Physiology sequence and the new Comparative Physiology course (starting Fall 2011).

**C. Other SEI activities in 2010**

1. Organized and implemented a formal Teaching Assistant for graduate students. This training will be continued in Summer 2011.
2. Manuscript entitled “*How Not To Lose your Students in Concept Maps*” was accepted for publication in the Journal of Science College Teaching.
3. Other manuscripts in preparation:
  - a. Anatomy Learning Inventory (ALI) – a tool to evaluate students understanding of basic anatomy concepts and misconceptions. Lead author Kate Semsar.
  - b. *CLASS (Colorado Learning Attitudes about Science Survey)* – a new tool to assess student beliefs about biology and learning biology. Lead author Kate Semsar.
4. Poster presentation “How physiology students value and use learning goals.” Lead author Teresa Foley. Poster to be presented in the Physiology Education Section at Experimental Biology Conference (April 2011, Washington D.C.)
5. Administration of department-wide survey on the use of learning goals by students. After working with a number of faculty working groups it became evident that faculty wanted to know how students use learning goals. A literature search about student use and value of learning goals was completed and a survey was conducted to assess the direct use in our department. The survey was conducted in four major courses and three independent scorers analyzed the results. Initial results of this survey suggest that students use learning goals to prepare for exams, organize the lecture material, actively quiz themselves, and to guide the reading of the textbook. Results from this survey will be written up for publication.
6. In the summer of 2010, two STF's had the opportunity to teach for the department. Franny Bentley taught a non-major Human Physiology course (IPHY 3430), and Teresa Foley taught an upper-division Immunology course (IPHY 4600). Both STF's implement SEI-promoted education tools. The success of these tools has encouraged other faculty to introduce these active learning techniques into their own courses. In addition, the faculty member teaching IPHY 4600 has changed her methods in class and increased the level of challenge on exams.

#### **D. Goals for Spring & Summer 2011**

1. Due to funding constraints, the department will only be able to fund 1 STF after May 1. This STF will continue to wrap-up any SEI projects including:
  - a. Finalizing a pre-post test for IPHY 3480.
  - b. Finalizing recitation activities for IPHY 4440 and 4600.
  - c. Finalizing development of laboratory activities for IPHY 3435.
  - d. Archiving course materials for IPHY 2800, 3060, 3470, 3480, 4440, 4600, and 4720.
  - e. Publishing any manuscripts in preparation.

## **VII. SEI in MCDB**

### **A. Departmental structure of the SEI program**

Dr. Jennifer Knight is the MCDB SEI Coordinator, and Distinguished Professor Bill Wood is the MCDB Director for the program. Drs. Jia Shi and Dr. Sarah Wise (hired in January '10) are current Science Teaching Fellows. Dr. Michelle Smith served as an STF until July '10, when she left for the University of Washington.

### **B. Course-related efforts**

#### **1. General**

All of the core MCDB courses now have:

- 1) Course- and topic-level learning goals. These goals were presented to the faculty at large in January 2009, and the faculty voted to adopt them as our core curriculum. The learning goals for each core course are shared with the students (usually on the course website), and frame the teaching of each course. The learning goals for several courses (Developmental Biology, Molecular Neurobiology, Immunology, and Intro) are still being modified, or have been modified over the past year.
- 2) Interactive learning such as use of in-class concept questions (clickers), small group activities, and/or co-seminar courses designed to give students a small group environment to practice solving problems, and formative assessment such as homework have been incorporated into all courses, to varying degrees. Two courses (Cell Biology and Molecular Biology) have primarily implemented only clickers. Four courses (Intro, Genetics, Developmental Biology and Molecular Neurobiology) have implemented all of these practices. Two concept inventories have been developed and published: the Genetics Concept Assessment (GCA) (Smith et al. 2008) and the Intro Molecular and Cell Biology Concept Assessment (IMCA) (Shi et al. 2010). An assessment appropriate for our capstone courses, to measure overall learning over the entire major, is under development.

We have also continued 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. Fundamentals of Human Genetics (MCDB 1041)**

MCDB 1041 is traditionally taught every fall by Dr. Jenny Knight. The typical enrollment is between 60-80 students. This is a course for non-majors that fulfills the Arts and Sciences distribution requirement for science. In '10-'11, it was switched to the spring semester. Thus, MCDB 1041 was not taught in '10. The research project described below was accepted for publication in '10, in combination with earlier data from the majors genetics course.

- a. **Assessments:** the GCA is used every year in this class, both pre- and post. This year we amassed all the data from CU on the GCA, and will be using it in a publication.

- b. **Research projects:** Which approach to asking in class concept questions is most effective for student learning? We previously showed that peer discussion enhances understanding of in-class concept questions (Smith et al, 2009). Preliminary data from the majors genetics course indicated that students who had increased understanding on in-class concept questions when peer discussion was followed by an instructor explanation. To explore whether peer discussion in combination with an instructor explanation also improves student retention on in-class concept questions, students in both the majors Genetics course (2150) and the non-majors course (1041) answered in-class concept questions in one of three different modes: 1. Peer discussion only, 2. Instructor explanation only, and 3. A combination of the two. This paper was recently published in CBE-Life Sciences Education. In brief, the data showed that students have higher in class learning gains with the combination approach in both majors and non-majors classes. When separated by overall performance on clicker questions (low, medium, high), students in all categories performed better with the combination approach, but several interesting differences between students and courses were revealed. Majors performed equally well with peer or instructor explanation, and significantly better with the combination, at all overall levels. Non-majors performed only slightly better with the combination approach if they were overall weak students. In both courses, overall strong students showed much higher gain in the combination approach than in the instructor only approach, suggesting that especially for strong students, it is important to have peer discussion.

### 3. *Introduction to Cell and Molecular Biology (MCDB 1150)*

MCDB 1150 is offered every fall semester, taught by Dr. Jennifer Martin and Dr. Nancy Guild. The typical enrollment is approximately 400 students. Nancy Guild runs the co-seminar that accompanies this introductory biology course (see more information below). Jia Shi worked with Jennifer Martin to address some of the student common misconceptions in the fall semester, 2010.

- a. Assessments: Use of the IMCA

The Introductory Molecular and Cell Biology Concept Assessment (IMCA) was published in the winter issue of CBE-Life Science Education in 2010. The instructors will continue to use this assessment as a pre-/post test in the fall semester, 2011. Since there will be two sections of the lecture course taught by the same instructors for the first time in fall, 2011, the instructors will have the opportunity to test a new teaching strategy in one section and compare students' learning gains to the other untreated section (control cohorts), and also compare results to previous semesters.

- b. Research studies: characterizing and remediating misconceptions through in-class questioning and discussion

Drs. Jia Shi and Jennifer Martin conducted this study in fall 2010. In-class questioning and discussion on diffusion and molecular movement through membranes helped identify and overcome misconceptions associated with these two fundamental biological concepts. Specifically, responses to one-minute paper questions revealed that over 90% of the students had misconceptions regarding these topics. These misconceptions were characterized and formed the basis for in-class

clicker questions. The instructors then devoted three non-consecutive classes using clickers, peer discussion, and instructor explanation to helping students overcome these misconceptions. At the end, over 80% of the students corrected their misconceptions as assessed through a written exam. We are in the process of collecting data to examine if students retained the correct concepts in the final exam two months after the in-class discussion. If this method (combining one-minute papers with clicker discussions) can be shown to be effective, it may be implemented for other concepts in Intro, or in other courses in MCDB.

#### **4. *Intro Co-Seminar (MCDB 1152)***

In the fall semester, 2010, Dr. Nancy Guild coordinated and five undergraduate teaching assistants led the MCDB 1152 co-seminars each week. In this course students meet in small groups and do small group activities such as solve problems and work with hands-on models (i.e., amino acid models). 171 students (almost half of the students from MCDB 1150 lecture course) enrolled in MCDB 1152.

#### **5. *Principles of Genetics (MCDB 2150)***

In Fall 2009, Michelle Smith worked with Tin Tin Su to expand an earlier study which examined learning during peer discussion of in-class concept questions (Smith *et al.*, 2009). In this follow up study, students answered a clicker question (Q1) and then discussed the question and answered it again (Q1ad). Then 3-5 days later they answered a similar question Q2. A preliminary analysis of the results revealed that students who answered Q1ad correctly had ~65% chance of answering Q2 correct a few days later. Michelle will be repeating this study at the University of Washington this summer to determine whether adding student reflection activities changes retention of the material.

#### **6. *Genetics Co-seminar (MCDB 2152)***

The genetics co-seminar provides student with small group problem solving opportunities. This course included 172 students during the spring 2009 semester and 51 students in the fall 2009 semester. Nancy Guild and Michelle Smith coordinated the course last spring and Christy Fillman (an instructor in MCDB) coordinated the course this fall. Undergraduate learning assistants led the course each week.

#### **7. *Cell Biology Laboratory Course (CBLC) (MCDB 3140)***

##### **a. Development of an assessment to measure student learning of “controls”**

CBLC was offered both fall and spring semesters. In the fall semester 2009 and continuing through the beginning of the spring last year, Jia worked with Dr, Michael Klymkowsky on assessment questions to evaluate students' understanding of both positive and negative controls in biological experiments.

This assessment was given to students who took the unrevised Cell Biology lab course (control cohorts) in the fall, 2009 and their performance was compared to that of students who took the revised Cell Biology lab course in the spring (experimental cohorts).

##### **b. Research studies**

We found that a high percentage of students had difficulty identifying experimental controls even after completing three university-level laboratory courses.

To address this issue, Jia and Joy Power (CB lab coordinator) designed and ran a revised CBLC in which students participated in weekly “experimental control exercises.” To measure student understanding of control experiments, we used a set of assessment questions described above; these were given to students prior to and following completion of either a standard CBLC or the revised CBLC. Not unexpectedly, the results indicate that the revised course led to greater improvements in students’ ability to identify and explain the purpose of control experiments. Based on these observations, we recommend that explicit and detailed discussions designed to identify the design and purpose behind control experiments become a standard component of all laboratory courses (this work is accepted for publication in July 2011 by IJ-SoTL)

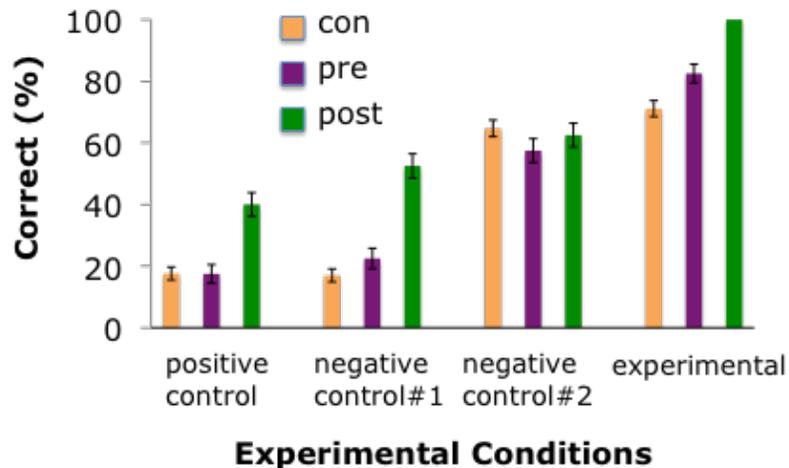


Figure 1. Comparison of students’ pre- and post-assessment performance in spring 2010 CBLC in identifying an example of a positive control, two different negative controls, and an experimental condition. The mean post-assessment score is significantly higher than the mean pre-assessment for the spring 2010 CBLC students (experimental cohort) and the mean score for the students at the end of fall, 2009 CBLC (control cohort; ANOVA;  $p < 0.001$ ). Control cohort (con) = 101 (without intervention). Experimental cohort = 40 (with intervention).

In the winter, 2010, Jia was invited to give a talk about the above study at the Purdue University: Introductory Biology Project Symposium – investigating students’ scientific reasoning about biological experiments.

### c. Development of a Scientific thinking survey

This survey grew out of the study on student understanding of controls in biological experiments (see above), and how little students understand about them. When we asked these questions of a multidisciplinary group of experts, it was clear that scientists in different disciplines also think about these problems differently depending on the constraints of their own fields. Jia, Jenny and Mike worked on the assessment questions based on the faculty responses. Jia also interviewed six students to get their feedback on the survey. This survey was finalized in February 2011.

We are interested in administering this survey to a larger number of students and faculty, and potentially exploring whether the different approaches that students and faculty take are dependent upon their majors/declines.

**8. Immunology (MCDB 4330) and Molecular Biology (MCDB 3150)**

Michelle Smith worked with Corrie Detweiler (Immunology) and Michael Stowell (Molecular Biology) to introduce clicker questions into their courses, develop pre-/postconcept assessments, and increase the Bloom's level of exam questions.

**9. Experimental Embryology (MCDB 4790)**

Although the use of clickers and peer discussion is becoming common in large-lecture undergraduate biology courses, their use is limited in small-enrollment seminar-style courses. To investigate whether facilitating peer discussion with clickers would add value to a small-enrollment seminar-style course, Michelle Smith, Caleb Trujillo and Tin Tin Su evaluated their usefulness in an 11-student Embryology course. Student performance data, observations of peer discussion, and interviews with students revealed that adding clickers to a small-enrollment course 1) increases the chance students will do the required reading before class, 2) helps the instructor engage all students in the class, and 3) gives students a focused opportunity to share thinking and to learn from their peers. This work was recently published (Smith et al., 2011).

**10. Molecular Neurobiology (MCDB 4777/5777)**

Sarah Wise worked with Kevin Jones to transform the Molecular Neurobiology course into a capstone course. Learning goals were co-written in January 2010 and revised significantly over the summer. Several clicker questions were written for each lecture of the course and catalogued over the summer. Conceptual exam questions and five conceptual homework assignments were added to the course, with the plan to expand these to ten assignments in the spring of 2011. Sarah provided feedback to Kevin from her observations of student clicker discussions and analysis of several student surveys. She also provided analysis of exams and homework using the Blooming Biology tool. Over the course of the semester the average Bloom level of exams in this course rose from predominantly Bloom level 1 and 2 items to predominantly Bloom level 2 and 3 items. Student attitudes toward clicker use and homework were positive. Dr. Jones' implementation of clicker questions was increasingly effective over the course of the semester.

**11. Developmental Biology (MCDB 4650) "Clicker Discussion Study"**

Sarah Wise developed a research project with Jenny Knight to assess instructional factors that could impact the engagement of students in clicker discussions. A quasi-experimental design was adopted whereby Jenny Knight varied the introduction of clicker questions. During a given week, the introduction would be "instructor centered", leading students to believe Jenny would explain the clicker question, or "student centered", leading students to believe Jenny could randomly ask their table to contribute an explanation. We hypothesized that student discussions would be more focused, involve deeper reasoning, and be more likely to come to consensus following a "student centered" introduction. With the help of Jia Shi, Katie Southard, Breanna Pritchard, and Noyce Fellow Julia Walden, clicker question

discussions at three student tables were video recorded during 17 Developmental Biology lectures in the fall of 2010. Two to three questions which initially split the student population were chosen for transcription, for a total of 88 separate transcribed conversations. Data on student engagement was also collected for each of the tables being recorded. Data analysis is ongoing in the spring of 2011 with significant progress made in the development and application of a coding tool to the transcripts.

### **C. Development of a Capstone Assessment tool for MCDB majors**

In discussions with MCDB faculty and the departmental Undergraduate Committee (UGCOM), we reached agreement that the best way to sustain and continue to improve research-based teaching in our core majors courses is to focus on developing an assessment tool that will allow us monitor whether our students are graduating with the skills and knowledge we believe to be essential. The development of a “capstone” assessment, administered each year to seniors and intended to measure students’ ability to integrate and apply their knowledge, will direct the attention of the faculty toward specific areas of difficulty and help to further shape our curriculum and our teaching. Instituting a process for periodic review and updating of core course learning goals will complement the capstone assessment effort, further insuring that the core courses are adequately addressing the overall learning goals of the program.

The MCDB capstone assessment will be designed with extensive faculty input (see below) to reveal persistent student misconceptions and areas of weakness that persist among our graduating majors students despite four years of instruction. The results will provide an annual incentive for the faculty to examine the effectiveness of our core courses and to sustain efforts at instructional improvement, as well as possibly identifying areas where broader curricular changes would be desirable. Details of how the assessment will be administered are still under discussion, but it would probably be given toward the end of students’ senior year, with suitable incentives to insure broad participation. It might also be administered during the introductory course to provide pre-test data, and could potentially be used as a follow-up assessment of students several years after their graduation to measure retention of their learning in the department.

Initial work on the capstone assessment has been funded by an iSTEM Chancellor’s Award to Jenny Knight. Caleb Trujillo worked with Sarah Wise and Jenny Knight to develop and carry out a student interview project aimed at generating questions for a Capstone Assessment tool for the MCDB major. Capstone Learning goals were drafted in the spring of 2010. Six MCDB faculty reviewed and commented upon the Capstone Learning Goals in interviews led by Sarah Wise and Jenny Knight during the summer of 2010. Seventeen MCDB majors who had completed the Core course sequence were recruited in the summer of 2010 to take part in two rounds of open-ended interviews on questions related to Capstone Learning Goals. Interview transcripts were transcribed and used to generate distractors for multiple choice versions of 25 questions, during the second round of interviews. A draft pre- and post-Capstone Assessment was administered to 115 Developmental Biology students in the fall of 2010, using multiple choice questions and space for students to comment on each question. On 18 of the pretest items, fewer than 65% of students chose the correct answer.

The proposed assessment will be designed to measure in-depth understanding and problem-solving ability, with questions targeted at the higher levels of Bloom’s taxonomy (application, analysis, synthesis, and evaluation).

Development of the assessment will continue following the steps below:

*Step 1:* Through faculty interviews, formulate a set of core learning goals that represent the major concepts and skills we expect students to learn in the core MCDB courses.

*Step 2:* With student interviews, collect answers to open-ended questions that address the learning goals.

*Step 3:* Focusing on concepts that students have difficulty with, create open-ended response and multiple choice questions, basing distracters and correct answers for the latter on student responses from Step 2.

*Step 4:* Administer a pilot assessment, interview additional students, and revise the assessment.

*Step 5:* Solicit evaluations of the questions from internal and external faculty; revise assessment as necessary.

*Step 6:* Repeat the student interview and faculty evaluation process.

*Step 7:* Administer second version of assessment to large number of students.

*Step 8:* Perform statistical analyses to determine evidence of validity and reliability of the assessment.

The process of creating an assessment tool has evaluation built in at each step (interviews, analysis of pilot assessment questions, expert review; see above). The expert review is particularly important for such an assessment, since its ultimate usefulness depends on its value to instructors within MCDB, as well as its possible value to similar departments at other institutions, to which some of our students may apply for graduate work. At least 5 faculty within MCDB will be asked to help evaluate the learning goals and questions as they are being developed, and at least 5 additional experts will be asked to review the pilot assessment once it is complete. Since many of our majors apply for admission to medical schools, we will also be guided as appropriate by the recent AAMC/HHMI report on competencies for future physicians.

#### **D. Faculty Presentations/Synergistic activities.**

Jenny Knight, Bill Wood and Michelle Smith are founding members of the recently formed Society for Advancement of Biology Education Research (SABER).

Tin Tin Su is continuing to conduct research on the use of clickers in her classes, and recently published a paper in CBE on the use of clickers in a small upper level course (Smith et al., 2011)

Bill and Jenny offered the Teaching and Learning Seminar (MCDB 5650) in spring '10. There were 24 participants in the class, including undergraduates, graduate students, and postdocs from five different departments.

Jenny was an invited speaker at the American Society of Microbiology Conference for Undergraduate Educators ("The power of teaching interactively and assessing student learning"), where she presented information on concept assessments in biology (CABs), their development, their use, as well as general information on group work and interactive teaching. Jenny also gave a workshop at ASM-CUE ("Techniques for Successfully Aligning Goals and Assessment"). Jenny was also an invited participant in the NSF-funded Concept Assessments in Biology Meeting in San Diego, and gave two faculty seminars, one at the Biology Department at Case Western Reserve University, and one in the Plant Biology Department at the University of Georgia. Jenny was also a

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

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, and the HHMI Science Education Advisory Board. 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 Harvard Medical School, Zurich Technical University, Switzerland, Cal Poly University, and the Howard Hughes Medical Institute.

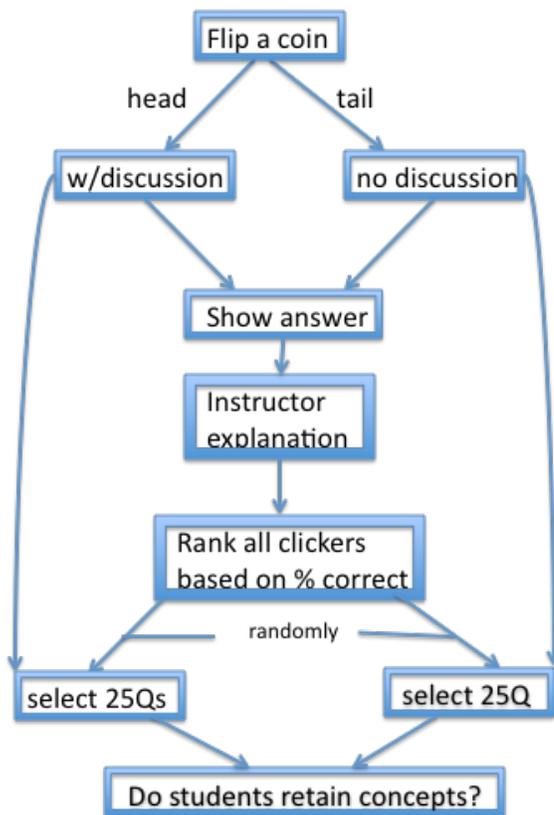
#### **E. Goals for 2011**

1. General:
  - a. The SEI group is finishing up several research projects. These will take precedence over other work until July.
  - b. In July, the SEI group will begin working primarily on generating and validating a Capstone Assessment in Molecular Biology.
  - c. The team will review learning goals with instructors of all courses, focusing on revisions and better integration of the curriculum.
  - d. The MCDB team will meet every other week in a lab-meeting type format.
  - e. Sarah Wise will host and moderate MCDB “Education Roundtable” discussions once a month to foster discussion of the curriculum, learning goals, and assessments.
2. Assignments for Jia Shi in 2011
  - a. Finalize papers (Intro misconception paper and the scientific thinking survey report)
  - b. Work with Tin Tin Su in the Experimental Embryology course (MCDB 4790). This is a small, optional critical thinking course.

#### **Hypothesis:**

If students discuss with their peers while answering in-class conceptual questions, they will retain knowledge better than students who answer conceptual questions on their own: learning through student peer discussion is directly related to retention.

Figure 1. A diagram of the proposed retention study in the Experimental Embryology course. Clicker questions are either used with or without peer discussion. After all questions have been administered and ranked based on percent correct, a random sample of clicker questions for which the initial % correct was similar will be chosen to re-ask at the end of the course.



If students' discussions have a positive impact on learning retention, Tin Tin may use this method in her future genetics course.

c. Work with Dr. Corrie Detweiler in Immunology (one of the capstone courses for the major; Developmental Biology and Neurobiology are the others), Fall 2011. This will be Jia's primary role for Fall, since she will be working only 10% time for the MCDB SEI. Corrie is particularly interested in understanding students' difficulties in Immunology. Specifically, Jia will look through examples of students' exams and interview students to find out common student's difficulties. She will also sit in Corrie's lectures to obtain more information on student learning and difficulties. This work will help further development of the capstone assessment.

3. Assignments for Sarah Wise in 2011:

- a. Support the continued transformation of Molecular Neurobiology with Kevin Jones. Align all curriculum with learning goals, revise and archive clicker questions, expand and convert homework to an online platform, support exam revision, and continue to work with Kevin Jones on effective clicker implementation.

- b. Moderate a monthly “Education Roundtable” with MCDB Faculty, with a focus on widespread participation in informal conversations about curriculum, misconceptions, assessment, and TA/LA support for courses.
- c. Analyze data associated with the Developmental Biology clicker discussion study. Develop and apply a coding tool to transcribed data with the assistance of Katie Southard and Breanna Pritchard. Prepare findings for publication.
- d. With Jenny Knight and Katie Southard, gather widespread faculty input on the Capstone Assessment. Pilot a finalized Capstone Assessment in either fall of 2011 or Spring 2012.

### **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.
- 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 (2011a) 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 (2011b). Combining peer discussion with instructor explanation increases student learning from in-class concept questions. *CBE-Life Sci. Educ.* 10,55-63.
- Wood, WB (2009) Innovations in teaching undergraduate biology, and why we need them. *Ann. Rev. Cell & Devel. Biol.* 25, 93-112.
- Accepted (under revision): Semsar K, Knight JK, Birol G, Smith MK. The Colorado Learning Attitudes about Science Survey (CLASS) for use in Biology. *CBE-Life Sci. Educ.*

## **VIII. 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 XXX, 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, Mihail 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. 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.

#### **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 our website ([http://www.colorado.edu/sei/departments/physics\\_3310.htm](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.

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\*\* Indicates materials which have been substantially revised or contributed to by instructors in Fall 2008 and later.

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 six CU instructors 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.

### **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.

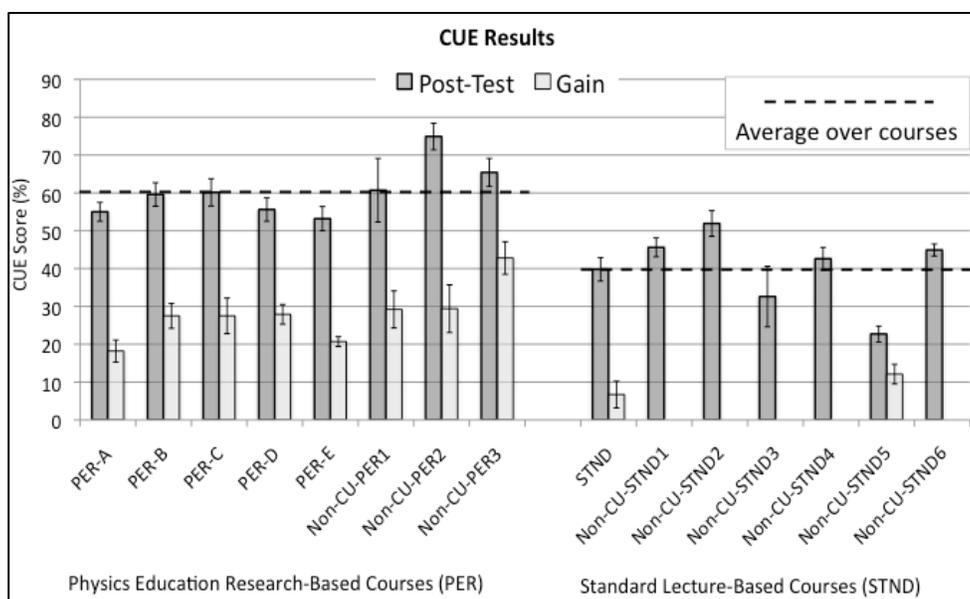
The CUE is an open-ended assessment developed based on faculty learning goals and common student difficulties. It is a 17-question test consisting of written explanations, conceptual reasoning, sketching, graphing, and a few multiple choice questions. A pre-test was developed based on a reasonable subset 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. Inter-rater 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  $\alpha$  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 6 semesters of E&M I students – Fall 2007 (taught traditionally: STND), and the 5-semesters of transformed (PER) courses: Spring 2008 (the first semester of transformations), Fall 2008, Spring 2009, Fall 2009, and Spring 2010 (successive iterations of transformations). The CUE post-test was also given in several external institutions, and graded for nine courses in six outside institutions. 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.

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 5 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<sup>1</sup>, 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
<b>Demographics</b>							
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).

<sup>1</sup> Except for Fall 2009, courses offered in the Spring semesters were composed of more physics majors and fewer engineering physics majors than the Fall semesters. Spring semester is also comprised of fewer students overall than Fall.

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.

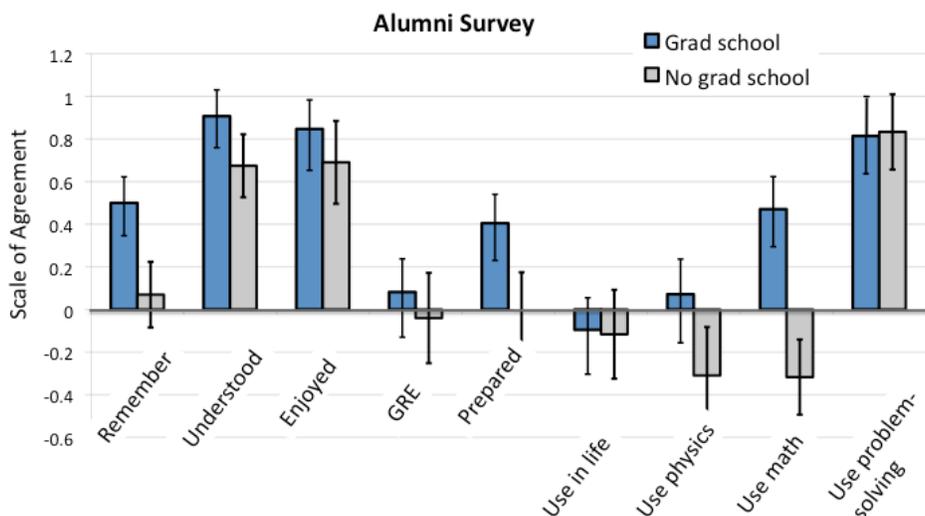
Lecture, clicker questions, and tutorials were most popular among students. Students (with the exception of PER-A) felt that the lecture was well-connected to homework and provided adequate instruction in mathematical techniques. While whiteboards were poorly rated by students, we have reason to believe 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 a 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?

## **2. *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 and Astrophysics as well as for the BS in Engineering Physics – about ??% of the course is populated by these majors. The remaining students are comprised of mathematics majors (??%), other natural science majors (?%), non-physics engineering majors (??%) and other miscellaneous and undeclared majors (?%). Typically, this course is taken by sophomores as their 4<sup>th</sup> course in the physics sequence, and the enrollment is ??? 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 the fall course Dr. Pepper also organized a weekly homework help session to both help the students and provide a place to observe their difficulties. In the spring, 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 will start in the spring of 2011 with Steve Pollock and Ana Maria Rey co-teaching the course.

Activities in PHYS 2210 include:

##### **a. Creation of learning goals**

As discussed further in section C3, a faculty working group facilitated by Dr. Pepper created both broad-scale and topical learning goals for PHYS 2210.

##### **b. The Intermediate Mechanics/Math Methods Assessment Tool (??needs a good name?)**

With the assistance of several faculty members, Rachel Pepper has developed both a pre and post-test assessment tool based on the most important learning goals selected by the faculty working group. Students took the post-test as an in-class diagnostic exam near the end of the Fall 2010 semester, and will take the pre-test in the spring of 2011. As currently developed, the diagnostic is open-ended, but the goal is to create a modular, multiple choice assessment so that the math methods and classical mechanics portions of the test can be administered independently.

##### **c. Course Materials**

Some clicker questions and in-class activities have been developed by Alysia Marino, Rachel Pepper, and Steven Pollock, but the bulk of new material creation and adaptation of existing materials will occur in 2011.

#### **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&M I 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 2011**

##### General:

- ???

##### Goals for work on 3310:

- Compile and analyze data on all 5 semesters of 3310, including tutorial attendance, BEMA, CUE, and attitudinal data. Write one paper for publication on this work the overall transformations and results of the transformations (for the American Journal of Physics), with the potential for another paper on sustainability of the transformations based on interview data.
- Compile and analyze data on the CUE, including completion of faculty and student validation interviews (ongoing). Write one paper for publication (for Physical Review Special Topics) on the CUE development and instrument.
- Compile data from interviews, CUE, and course observations, and complete additional interviews as needed, to develop a more complete and detailed list of student difficulties and ideas (e.g., “misconceptions”) on the topics in 3310. Publish one paper on common student difficulties in upper division E&M.
- Refine pre- and post-tests for individual tutorials.

##### 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.

##### Goals for work on 2010:

- Run a transformed version of phys 2210, including creating new clicker questions, homework questions, in-class activities/tutorials, exam questions, and pre-class activities.
- Organize and archive the newly created bank of course materials for later use.
- Refine, administer, and validate the intermediate mechanics/mathematical methods conceptual post-assessment tool.

- Investigate student difficulties through weekly homework help sessions, individual student interviews, and small-group student interviews.
- Write at least one paper (PERC) about this process and/or results from the transformation.

- 

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.

