

**2009 Annual Report**  
**for the**  
**CU Science Education Initiative**

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## 2009 Executive Summary of CU's Science Education Initiative

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

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

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

After 4 years, a significant number of faculty in 5 departments (CHEM, GEOL, IPHY, MCDB, PHYS) have been impacted by the SEI, modifying their teaching, creating and using learning goals, and using information on student thinking to guide their teaching. Faculty are engaging in research-based teaching methods and educational issues. The SEI project has also impacted a large number of courses, through in-depth interaction with faculty teaching those courses, developing learning goals in collaboration with faculty, and developing and administering validated assessments of student learning. These changes have impacted over 10,000 students per year, considering courses in which STFs have been both fully and partially involved. The SEI has also impacted departmental culture, affecting the frequency of discussions about teaching and learning in departments, and leading to numerous grants to continue the work begun by the project.

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

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

## **I. Overview of the Science Education Initiative**

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

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

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

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

Below, we provide details on the central SEI activities that are being conducted in support of the project, followed by a summary of the SEI budget. In the last five sections, the participating departments (Chemistry, Geological Sciences, Integrative Physiology, MCDB, and Physics) summarize the structure of the SEI project within their department, the course-related activities in 2009, faculty involvement in the SEI, and departmental goals for 2010.

## **II. Central SEI Activities**

### **A. Update on central staffing**

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 2/3 has been devoted to outreach.

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, and workshops to faculty within SEI departments and the university as a whole.

#### **D. Publications and talks**

Over the past 4 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 complete list of papers from the SEI can be found at <http://www.colorado.edu/sei/publications.htm>, or in later reports.

## E. 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

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.

These videos are housed at <http://STEMclickers.colorado.edu>, and on YouTube at <http://www.youtube.com/user/geekgirl54>, as well as on the CU Boulder iTunesU site. 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.

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

#### 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. This 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.

### **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 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 2010**

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.

## F. Other 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. 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>

#### **G. 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.

## IV. SEI in Chemistry

### A. Departmental structure of SEI program

#### i. People

Faculty Director: Professor Robert Parson.

Chemistry Education Specialists: Dr. Laurie Langdon (all year), Dr. Thomas Pentecost (Jan 1 2009 - Jul 31 2009). In August Dr. Pentecost took up a tenure-track faculty position at Grand Valley State University in Michigan.

Faculty Working Groups: see below.

#### ii. Departmental structures / decisions

Overall departmental oversight is provided by the Chair, Professor David Walba (Jan-Jun 2009) and Bruce Eaton (Jul 2009-present), and the Executive Committee, Professors Tad Koch, Veronica Bierbaum, James Goodrich, and Bruce Eaton. Senior Instructor Dr. Margaret Asirvatham is Director of the General Chemistry Program. Senior Instructor Dr. Susan Hendrickson was hired in Fall 2007 and has her major teaching responsibilities in General Chemistry. The Undergraduate Curriculum Committee (Professors Parson, Kevin Peters, Ray Fall, Robert Kuchta and Robin Knight, plus Drs. Asirvatham, and Hendrickson,) advises the Chair in matters involving new courses. A General Chemistry Working Group was established in October 2006 to deal specifically with issues related to the SEI. Its present membership consists of Professors Parson, Thomas Cech, James T. Hynes, and Daniel Feldheim together with Drs. Asirvatham, Susan Hendrickson and Matthew Wise (instructors), Drs. Christine Kelley and Lynn Geiger (instructors and academic advisors), Laurel Hyde and Hannah Robus (Laboratory Coordinators) and Drs. Langdon and (until August 2009) Pentecost.

### B. Course-related efforts

During 2009, SEI Chemistry was primarily involved with creating a new lower division course (Chem 1251) and with assessing the transformation of the upper division Physical Chemistry courses. Involvement with the regular General Chemistry sequence continued, but at a lower level than in previous years.

#### i. Lower Division Courses

##### a. *CHEM 1111, General Chemistry 1.*

##### 1. Background

Chem 1111 is the standard beginning chemistry course for science majors and premedical students. With more than 1300 students per year it is not only the largest course in the department, but also the largest 5-credit course offered by the University. Most of these students take it during the fall term, when three lecture sections are offered, together with 40-45 recitation and laboratory sections overseen by 20-25 teaching assistants. In recent years the fall lecture sections have been team-taught, with one faculty member teaching all three sections for a portion of the semester, and then passing it on to another; all members remain actively engaged in

laboratory, office hours, and examinations throughout the course. (During spring and summer terms, a single lecture section is offered.)

## 2. Learning Assessment: instruments and findings

### i. Attitudes

The CLASS survey of student attitudes, which has been administered to General Chemistry students since beginning in 2004, has revealed that students perceive the subject to be non-intuitive, lacking in logical structure, and irrelevant to daily life. It also 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.)

### ii. Concepts

In spring 2006, Professor Katherine Perkins and Dr. Linda Koch, in consultation with Dr. Asirvatham, developed a Chemistry Concept Survey, based upon validated literature sources. This instrument has been revised in successive terms after faculty working group discussions. It was administered in both spring and fall terms of 2009. Learning gains were about 30% in Fall 2009, similar to Fall 2008 (and significantly higher than the 15-20% gains prior to Fall 2008.)

## 3. Changes in course instruction

### Lecture:

No major changes were made in 2009.

### Recitation:

The tutorials developed in previous years by Dr.'s Langdon and Pentecost were refined. Two undergraduate Noyce Fellows worked with Dr. Langdon to develop a Tutorial Handbook for Teaching Assistants and Learning Assistants. The handbook includes general guidelines about the purpose and structure of the tutorials, together with a set of heavily annotated tutorial worksheets. The annotations include suggestions about how to implement each tutorial, observations about common student difficulties, and some examples of student work.

Laboratory: Dr. Christine Kelley (Instructor and Academic Advisor) made extensive revisions to the Laboratory Manual for this course. Preliminary learning objectives were stated for each experiment. Critical thinking questions, to be answered in real time during the lab experiment, were interspersed through the instructions, and more conceptual prelab and postlab questions were included. These revisions were intended to better focus student attention on the instructional goals of the lab. In Spring 2009, two undergraduate Noyce Scholars, with the advice of Dr. Langdon, developed two new experiments for this course. These experiments were designed on

the basis of agreed-upon learning goals. They were first used in Summer 2009, and one of them has been incorporated into the curriculum.

#### 4. 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, it was given to all entering graduate students. Hannah Robus, the Laboratory Coordinator for Chem 1111, and Dr. Langdon directed the training.

### ***b. CHEM 1251, General Chemistry 1 for Majors***

#### 1. Background

In 2008, the Department decided to create a new General Chemistry Sequence for Chemistry and Biochemistry majors. There were several reasons behind this decision, of which the most significant were the desire to create a "learning community" among the majors, who have previously been dispersed within the much larger population of nonmajors, and to make general chemistry teaching more attractive to tenured and tenure-track faculty. Professor Thomas Cech volunteered to teach the course in Fall 2009. (Dr. Cech, a CU Distinguished Professor and Nobel Laureate, had been on leave for the past 10 years, during which he directed the Howard Hughes Medical Institute.) Professor Daniel Feldheim volunteered to teach the successor course, Chem 1171. Drs. Cech and Feldheim met with Dr. Langdon several times during the summer of 2009 to discuss various aspects of course design and implementation. Approximately 100 students took the course in Fall 2009.

#### 2. Learning Goals

In Fall 2009, the content of the new majors' course was very similar to that of the main general chemistry course, Chem 1111, so the Course and Lecture level learning goals were largely retained. However, they were augmented with a set of "big ideas" that Dr. Cech proposed as unifying elements for the course. Dr. Cech also designed four "Career Scenarios" to demonstrate how the concepts discussed in class could arise in real-world situations. These scenarios were presented in class.

#### b. 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 1111). The normalized learning gain in the Concept Survey was 37%, the highest that has yet been obtained using this instrument.

#### 3. Changes in course instruction

Lecture: Professor Cech used the same overall strategy that has been deployed in the regular General Chemistry sequence: lecture with interspersed clicker questions. Dr. Langdon assembled the clicker questions from sets developed by current and



previous General Chemistry instructors. The major departure from previous practice in the department was the creation of "clicker teams" - after the first few days, students were asked to form teams of 3-4 students who would as a rule work together on each clicker question for the duration of the term.

Recitation:

Recitation used the tutorial format developed in previous years for the regular General Chemistry sequence. Some of the tutorials were revised, however, and a few new ones were created specifically for this course. Interactive PhET simulations were used as an integral part of one recitation.

Laboratory: The Laboratory component of the course was the same as for Chem 1111.

### *c. CHEM 1131, General Chemistry 2*

#### 1. Background

This is the successor to CHEM 1111. It is taken by approximately 800 students per year; students must pass CHEM 1111 with a grade of C- or better in order to register for CHEM 1131. 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 1111 apply to CHEM 1131 as well, and will not be redescribed here.

#### 2. Description of ongoing activities

a. Learning Assessment: CLASS and Concept Surveys were given again in 2009. The results are similar to previous years, and have not been analyzed in depth.

#### b. Changes in Course Instruction

Transformation of instruction in CHEM 1131 began in 2007, and followed a similar path: improvement of concept tests, transformation of recitations into tutorials and introduction of learning assistants. No major changes to the lecture component were made during 2009.

A handbook for the Recitation tutorials, similar to that developed for Chem 1111, was begun and is expected to be complete by the end of Spring 2010. The Laboratory component was revised along the lines described above for Chem 1111. Professor Parson assisted Dr. Kelley in this endeavor. A graduate student, Marta Kapala, carried out systematic observations of student work and discourse during two of the laboratory experiments, dealing with oxidation-reduction reactions and electrochemistry, and administered a conceptual test (based upon published observations about student difficulties in this area) to a few of the sections, in order to get a sense of whether the students understood what was happening in their experiment.

***d. CHEM 1021, Introductory Chemistry***

This course is taken primarily by students who need additional instruction in basic chemistry before taking Chem 1111. Some of these students have had no high school chemistry at all, some have been out of school for many years, and some have decided (or have been advised) that they need more preparation. In Summer 2009, Dr. Kelley, with help from Drs. Hendrickson and Langdon, initiated a major transformation of this course. Recitations were converted to a tutorial format, following the model developed for the main general chemistry sequence. Chem 1111-1131. The laboratory manual was rewritten so as to include more critical thinking questions before, during, and after the experiments. The major role of SEI was to catalyze this transformation - most of the groundwork was carried out by faculty employed by the Department.

***e. Upper Division: CHEM4511 and 4411, Physical Chemistry***

1. Background

In 2008 SEI-chem 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. Chem 4411 is directed towards biochemistry majors while Chem 4511 is directed towards chemistry majors, but in practice the course populations are very similar. This work continued during 2009, primarily during the spring term (during Fall 2009 nearly all SEI resources were devoted to Chem 1251.) Professor Veronica Vaida taught Chem 4511 in spring and fall 2009, while Professor Amy Palmer taught Chem 4411 in Fall 2009 (this course is not taught in the spring term.)

2. Assessment

A concept survey, focused on areas common to both courses, was developed Professor Parson, Professor Amy Palmer, and Science Teaching Fellow Thomas Pentecost in summer of 2008. This was administered to both courses in Fall 2008 and Fall 2009 and to Chem 4511 in Spring 2009 Dr. Pentecost interviewed students about questions in this survey in Fall 2008 and Spring 2009. From these interviews it became apparent that some of the questions dealing with Free energy and the Second Law of Thermodynamics were ambiguous and were changed. The interviews revealed student difficulties with interpretation of heat, work and energy that are consistent with observations in the published literature.

3. Changes in course instruction

Professors Vaida and Palmer used two distinctly different interactive engagement strategies in their courses. Professor Vaida used a peer instruction model (lecture interspersed with clicker concept tests) while Professor Palmer. In Chem 4411, Palmer used breakout sessions, in which students solved conceptual problems in small groups, as a part of each class period. These models had been introduced

into the class in previous years (breakouts by Professor Palmer in 2007, peer instruction by Professor Parson in 2008) and no major changes were made in 2009, but both models were refined based upon observations and results of assessments. An examination of the concept survey results from Fall 2008 revealed that students in Chem 4411 did much better than students in Chem 4511 on a few questions. Examination of course materials revealed that the concepts targeted by these questions had been explicitly addressed by the 4411 breakout activities. Professor Parson and Dr. Pentecost designed clicker questions to address these points, and these were administered in Chem 4511 during Spring 2009. The result of this intervention was a dramatic improvement in the corresponding concept survey results – for example, the post score on a conceptual question about heat capacities went from 35% to 79%.

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

To this point, Faculty from the Department have been involved in SEI activities either on an individual basis or through the Working Group. Parson and Langdon have each made presentations at Faculty meetings, and these have prompted some discussion, but the primary lines of communication have been contacts with individuals. More and more these contacts have been initiated by Faculty, showing a gradual increase in the SEI's visibility within the department.

### **D. Goals for 2010**

1. Assist in the development of the second semester of the new Majors General Chemistry course. Professor Daniel Feldheim, who is using the tactics pioneered by Professor Cech and Dr. Langdon in the first semester, is teaching this.
2. Begin involvement in the second semester of the Physical Chemistry Sequence, Chem 4531. Professor Matthias Weber is teaching that course this semester, and a graduate student, Marta Kapala, with interests in science education is helping him to develop group activities and clicker questions, as well as adapting conceptual and attitude surveys developed for Physics courses that cover similar material (elementary quantum mechanics.) This work is partially supported by an NSF CAREER award to Professor Weber.
3. Continue the gradual transformation of the laboratory in General Chemistry. The free-response test of student conceptual understanding of electrochemical cells has been converted to a multiple-choice version (with distracters taken from common student responses) so that it can be given to a larger number of students.
4. Collect, evaluate, and archive course materials.
5. Write up major results 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 4<sup>th</sup> full academic year. The program has become an integral part of the teaching mission of the department and is now a widely utilized resource and advisement base for faculty.

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. Dr. Budd was on sabbatical leave from January through June, 2009. Professor Stephen Mojzsis served as Acting Director of SEI-GEOL during that time period.

### **B. Human Resources**

In 2009, we continued to have three postdoctoral STFs present in the department to implement SEI-GEOL strategies across a wider range of undergraduate courses. The three STFS in the spring and early summer were Dr. Andrea Bair, Dr. Jennifer Stempien and Dr. Leilani Arthurs. Dr. Stempien's contract with the SEI ended at the end of June 2009 and she accepted a position as a Visiting Assistant Professor in Geology at Washington and Lee University. A national search for a replacement was conducted in the spring of 2009 and Dr. Michael Vredevoogd, a recent PhD recipient in Geophysics from the University of California, Riverside was hired effective August, 2009.

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

The SEI-GEOL has pursued a two-prong 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, and all of our attendant rank 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 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). Accomplishments in these courses are detailed below.

As noted in our 2008 report, 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 Activities**

### *a. Introductory courses*

#### **1. 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 but one of the five instructors had worked, to varying degrees, with STF Stempien in 2007 or 2008 to implement these changes.

- Professor Jaelyn Eberle was the final GEOL 1020 instructor to take on the transformations outline above, and she did so in the spring of 2009 with STF Stempien's assistance. In addition to restructuring the content of the course and writing her own lecture-level learning goals, Dr. Eberle developed new homeworks and in-class activities, and increased the congrate level of her formative clicker assessments.

- A final summary report that outlines all transformation implemented by the various instructors of GEOL 1020 was prepared and deliver to the faculty by STF Stempien in June 2009. Highlights of that report include guidance on (i) how students are (not) using the textbook, (ii) ideas further improving homeworks, (iii) a review of successful examples of clicker use in the course, (iv) an assessment of student reactions to in-class activities, (v) a list of student identified learning difficulties, and (vi) examples of the better lists of lecture-level learning goals defined by the five faculty instructors.

#### **2. 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 curricullum. 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.

- In 2009, STF Arthurs began working with Dr. Abbott and they drafted a comprehensive set of learning goals for the entire course and each lab activity. With Arthurs' editorial assistance, Dr. Abbott began writing a new lab manual for the 15 exercises in the course that incorporate these learning goals and will make the lab exercises more centered on student activities rather than TA-guided exercises. Two chapters were finished by the end of 2009 and the manual should be complete and ready for use in Fall 2010.

- STF Arthurs developed and validated an initial set of 14 questions for a pre/post conceptual diagnostic test. This concept survey will be implemented in spring 2010 and revised further as needed.

- Learning assistants were first utilized in GEOL 1030 in the 2006-2007 academic year and their use in this course continued to grow in 2009. STF Arthurs attended all LA Program meetings and held weekly meetings with the five GEOL 1020 LAs, providing them support with respect to geology content knowledge and pedagogical approaches in the lab and field-trip environments.

### 3. *Environmental Geology (GEOL 2100)*

- Professor Alexis Templeton and STF Arthurs implemented numerous transformations in this course in 2007 and 2008, making the first course in Geological Sciences that we could consider "completely" transformed with respect to the objectives of the SEI. In 2009 Drs. Templeton and Arthurs developed and validated (through student interviews) a few additional concept inventory questions for the course. In addition, Dr. Templeton introduced peer learning assistants to the course.

#### *b. Upper-Division Courses*

### 4. *Introduction to Mineralogy (GEOL 3010)*

- STF Dr. Andrea Bair, Prof. Joseph Smyth, and the teaching assistants for this course partnered for a second semester to complete the transformation of the laboratory component of this course. This effort began in 2008 with a focus then on both the lecture and laboratory components of the course. Course, topic, and lecture-level objectives and learning goals were established in 2008. The major focus and accomplishments in 2009 were (1) complete learning goals for all labs, (2) reform of the lab exercises to support more active learning and higher cognate levels of learning, (3) improve connections between concepts covered in lecture and labs, and between labs, (4) improve components of all lab exercises that were identified in 2008 student interviews as confusing, poorly structured, or ineffective, (5) identify student learning difficulties, and (6) align quizzes and lab exams with revised content and goals of lab exercises.

- Drs. Bair and Smyth met weekly with laboratory TAs to discuss likely student learning difficulties, examine past laboratory materials, and modify laboratory activities to better reflect scientific teaching. New labs on mineral symmetry and key mineral groups were developed, as was a new final lab exercise designed to help students integrate and apply critical concepts learned during the entire semester. Observations by TAs, instructor, and STF strongly suggests that these reforms were successful in scaffolding concepts. The TAs also observed that students spent more time on the labs than last year, which is a desirable outcome.

- Documentation of the reformed laboratory will be completed in spring 2010 and will include all necessary information on lab setup, implementation, student learning difficulties, potential further improvements to lab exercises. This material, as well as all lab exercises and accompanying learning goals will be placed in the SEI archives.

#### **5. *Introduction to Oceanography (GEOL 3070)***

- In 2007 and 2008, Professor Tom Marchitto and STF Leilani Arthurs collaborated to establish learning goals for this course, begin development of a pre/post instruction concept inventory to measure student learning gains, identification of student learning difficulties, and baseline data were collected from student observations and interviews on the presentation of this course without iClicker technology.

- In 2009, the existing learning goals and the baseline information on learning difficulties and student perceptions were utilized to assist the implementation of clickers and the development of clicker questions. Observations of student behavior and comments during lecture were used to revise clickers for future use. Based on lessons learned in 2008, the concept inventory for the class was also finalized in 2009. Comparison of the 2008 learning gains (no clickers utilized) and 2009 learning gains (clickers utilized) revealed no statistically significant differences.

- A 44-page report summarizing all finding in 2009 relative to student learning difficulties and the implementation of clickers was prepared by STF Arthurs and given to Professor Marchitto in December 2009. Highlights include (1) documentation of 23 separate concepts that provide difficulties for students, (2) suggestions for what students and Dr. Marchitto can do in future classes to address these difficulties, and (3) ways in which Dr. Marchitto can maximize the effectiveness of clicker usage in his class.

#### **6. *Structural Geology (GEOL 3120)***

- In 2008, STF Jennifer Stempien worked with Professors Karl Mueller and Kevin Mahan, and two TA's to define learning goals for the laboratory component of this majors-track course, and to create a new set of corresponding lab activities. The new activities focused on inquiry-based learning and presented authentic structural problems to the students. STF Stempien observed lab sessions and recorded her observations and suggestions for further improving the labs.

- In 2009, new STF Mike Vredevoogd worked with the same professors and that year's group of TAs to modify the labs based on the observations provided by Stempien. Modifications included changing the order or wording of lab questions to make them clearer to the students and/or to provide better scaffolding.

- Vredevoogd also worked with the TA's to make the presentation and supervision of the labs more inquiry based, and he observed students during the labs in order to further assess the effectiveness of the activities.

- After two semesters of effort, the laboratory component of the course is considered transformed and the revised laboratory exercises have been compiled into both electronic and hard copy archives for use in future classes.

## 7. *Paleobiology (GEOL 3410)*

- STF Dr. Andrea Bair assisted Professor Dean Smith in the initial effort to transform aspects of this majors-track course that is also well subscribed by biology and anthropology majors. Goals were to (1) develop an initial set of learning goals for the course, including overall course-level learning goals, learning goals by content area, and learning goals for each laboratory activity, (2) document student learning difficulties, (3) develop ideas for clicker questions that could be implemented in the future, (4) collect and archive teaching and assessment materials from both instructors teaching the course, (5) analyze how lab activities might be modified to better match overall course goals, (6) revise some aspects of the lab activities and assessments for internal consistency, and (7) guide the TA to lecture less in the labs and allow students more time for group work and interaction.

- To achieve these goals, weekly meetings Dr. Bair held weekly meetings with Prof. Smith and the TA. All labs now have learning goals, and a draft of overall course learning goals was developed. All lab exercises were also revised to improve internal consistency and improve interaction. Some areas of student learning difficulty were also identified for future consideration.

- Two major challenges to reforms in this course were identified by both students and the STF: 1) students have little opportunity to actively work with or apply the concepts covered in lecture, and 2) little overlap is apparent between lecture and lab for the majority of the course, which impedes focus and student learning for the systematic labs (and also does not provide opportunities for more active learning of concepts covered in lecture). These challenges are compounded by the fact that two different instructors teach the course in alternating years, with at least one of those instructors resistant to significant change.

- In Spring 2010, Dr. Bair will be working with Dr. Karen Chin, the other course instructor, to develop models for reforms that address these two major challenges.



## **8. *Fluid Earth (GEOL 3820)***

- Fluid Earth is a relatively new course, developed by Professor Greg Tucker for the Department's revised major track in Environmental Geology. This class was taught for just the second time in the fall of 2009, and STF Vredevoogd worked with Dr. Tucker to (i) create a list of learning goals for the course, (ii) develop and administer an initial pre and post concept survey to the class, (iii) introduce whole class and small group discussions to cover weekly reading assignments, and (iv) develop weekly homework that focused on a few synthesis questions

- Interviews of students during the course of the semester revealed that (i) students preferred the large group format of discussion; (ii) including guiding questions with the readings helped the students focus their discussions on the desired parts of the reading; (iii) revising homework to include scaffolding questions prior to asking more complex questions resulted in greater comprehension of the entire homework; (iv) that the first part of the course was too abstract for most students to comprehend the key concepts; and (v) many students are struggling with the basic calculus concepts needed for the course.

- Plans were made for the next iteration of the course to include (1) a calculus review for interested students in the first few weeks of class, likely during office hours, (2) addition of scaffolding questions to all the homework sets, (3) allocation of more time for students to complete the homework sets, so that they have a chance to ask questions about it during class, and (4) reordering of topics so that units the students found concrete and accessible (e.g., stream flow) will be covered first. Student interviews will be used to determine if this helps them bridge to more abstract concepts later in the course.

## **9. *Critical Thinking: Rates and Dates in Earth Science (GEOL 4500)***

- Professor Rebecca Flowers, who was one of the more aggressive faculty members in implementing aspects of the SEI in her introductory courses, requested assistance in the development of a new critical thinking course for Geology majors in spring 2009. STF Andrea Bair assisted Professor Flowers in this goal, first developing learning goals and assessing possible readings and themes for inclusion in the course. Pedagogically, they focused on developing assessment materials to determine student background experiences, conceptual and skill development, and attitudes.

- Of particular importance was evaluating student's ability to read scientific papers for understanding and critical analysis, and their ability to reason scientifically and communicate their thoughts. Based on insights from the published education literature, course material was prepared to specifically address these issues. Surveys and student interviews were used to assess effectiveness. Results indicate that students improved in their confidence and competence in these areas.

- The instructional strategies and assessment materials developed are applicable to other courses in Geology and were adapted for use in Writing in Geology (GEOL 4969, taught by Professor Flowers), another critical thinking course

(Spring 2010 taught by Senior Instructor Lon Abbott and Professor Peter Molnar), a critical thinking courses in IPHY (Fall 2009), and Vertebrate Paleontology (GEOL 4474/5474, taught by Professor Jaelyn Eberle).

## **10. Other Accomplishments**

In prior years, the GEOL-SEI had already

- facilitated iClicker support and training for all departmental faculty,
- established a monthly luncheon seminar series on relevant SEI topics,
- proposed and implemented a Tutoring and Study Room (T&SR) for geology majors,
- assisted with the development of interactive simulations (PhET),
- researched and wrote a white paper for faculty on student attitudes and motivation coming into introductory geology courses,
- developed and presented a teaching assistant summer training workshop, and
- assisted with the implementation of peer learning assistants in select courses.

To varying degrees these activities continued in 2009. Notable accomplishments include:

### **1. Tutoring and Study Room**

○ In spring 2009, STF Arthurs continued to oversee the Tutoring & Study Room (T&SR) with ~10 departmental paid tutors who, collectively, were able to assist in 21 different GEOL courses. Data were collected on the number of students using the T&SR, for what courses they were seeking assistance and the reason for their visit (e.g. homework, test preparation, general confusion with course material). This data was combined with similar data from 2008 to create activity reports for the tutors and Department (e.g. Chair, GEOL-SEI director, Departmental Executive Committee), which in turn lead the Department to judge the T&SR a success that needed to be sustained independent of the SEI.

○ In Fall 2009, operation of the Geology T&SR was turned over to the Department. At that time the department began investing a 0.25 teaching assistantship to this program in the role of Head Tutor and a permanent room was established. STF Arthurs continues to mentor the Head Tutor.

### **2. Teaching Assistant Summer Training Workshop**

○ The 1.5 day TA training workshop, unveiled in 2008, was held in August, 2009, to introduce best pedagogical practices to teaching assistants. Participant evaluations showed that the TAs all found it very useful.

○ To support the 2009 workshop, STF Arthurs developed a 125-page manual titled, “*Teaching 101: The Basic Nuts ‘n Bolts & an Introduction to Pedagogy: TA Training Workbook*”, that will be distributed again in all future TA training workshops. TAs from the 2009 workshop report that this manual has been a valuable resource for them.

- As a follow up to the summer training, STF Arthurs held biweekly teacher training meetings with the GEOL 1030 TAs between the first and eleventh week of the semester. These meetings provided the TA to re-explore principles covered in the summer workshop within the context of their ongoing teaching experiences.

### 3. Classroom Demonstrations

- Demonstrations of various geologic process are utilized in variety of geology courses ranging from GEOL 1010 to the most advanced 4000-level courses. The faculty were queried as to the demonstrations that they use and all responses were compiled into a new document that identifies the goal of each demonstration, materials needed, where there materials can be found (or are stored), how to set up the demonstration, questions to pose to the students about the demonstration, and suggestions for linking the demonstration to key geologic concepts. The document, bound and distributed to all faculty, is:

L. Arthurs, M. Heepke, A. Bair, S. Mojzsis, D. Budd, and J. Stempien, 2009, *Geology Classroom Demonstrations: Geological Sciences - Science Education Initiative*, University of Colorado at Boulder; 53 p.

#### D. 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 2009, the faculty engaged with STFs on a significant level (designing, implementing, and/or evaluating various SEI objectives and/or approaches) were:

- Rebecca Flowers
- Dena Smith
- Joe Smyth
- Tom Marchitto
- Alexis Templeton
- Lon Abbott
- Jaelyn Eberle
- Karl Mueller
- Kevin Mahan
- Greg Tucker

In addition, faculty engaged by STFs on an advisory role were:

- Jason Neff
- Stephen Mojzsis
- Mary Kraus

#### E. Goals for 2010

##### 1. GEOL 1010, Introduction to Physical Geology and GEOL 1020, Introduction to Earth History

- STF Vredevoogd will develop two or three new in-class activities for GEOL 1010 in cooperation with Professor Kevin Mahan who is teaching one of four sections of this course in the spring of 2010. These new activities will extend the inventory of materials available for faculty use, as well as the content areas covered by the materials.
- STF Vredevoogd will also re-examine all existing GEOL 1010 activities with the intent of revising them as needed based on faculty and student input over the past two

years. Each activity will also be revised so that they can be implemented with respect to varied levels of faculty learning goals (i.e., for lower cognate levels of accomplishment as well as higher levels).

- Vredevoogd will conduct student interviews to assess the clarity and effectiveness of new and existing in-class activities.
- In response to faculty inquiries about the potential addition of recitation to both GEOL 1010 and 1020, STF Vredevoogd will develop 8 to 10 recitation exercises for GEOL 1020 in the spring of 2009 based on key concepts and the established learning goals of that course. In the Fall of 2010, Professor David Budd will then teach two sections of GEOL 1020 – one with three lecture periods per week and one with two lecture periods and one recitation section per week. The later will implement the newly developed recitation activities. Assessment tools (surveys, observations, interview protocols) will be developed to determine the impact and effectiveness of the recitation model.
- A similar experiment will be run in spring 2011 for GEOL 1010 using the already developed in-class activities for that course, and a report will be generated based on the outcomes of both experiments for the Department. The report will articulate the pros and cons of implementing some type of recitation model in these courses so that the Department can make a more informed decision as to how to proceed and allocate resources.

## **2. GEOL 1030 - Introduction to Geology Lab**

- STF Arthurs will continue working with Senior Instructor Lon Abbott as he completes the new lab manual for this course.
- Arthurs will develop additional concept inventory questions based on the new exercises written by Abbott.
- Arthurs will continue to support the LAs working in this course.

## **3. GEOL 3040 - Global Climate: The Geologic Record**

- STF Arthurs will teach this course in spring 2010 as its regular instructor, Dr. Gifford Miller, has taken on a 3-year assignment as Associate Director of INSTAAR.
- Arthurs will implement a full SEI transformation of the course, including (1) articulation of learning goals, (2) alignment of the existing lectures and assessments with those learning goals, (3) introduction of interactive activities to the lecture (e.g., clickers, in-class exercises) to facilitate student learning, and (4) collection of student data in order to develop an initial pre-post concept inventory.

## **4. GEOL 3410 - Paleobiology**

- In spring 2010, STF Bair will work with Professor Karen Chin to improve the initial set of learning goals developed for this course by Professor Dean Smith.  
STF Bair

- STF Bair will also develop ideas and materials to address the two major challenges of this course noted above (i.e., students have little opportunity to actively work with or apply the concepts covered in lecture, and there is little overlap between lecture and lab for the majority of the course). Bair will attempt to develop materials and suggestions that can be implemented by both Drs. Chin and Smith, who have extremely different approaches to this class.

## **5. GEOL 3430 - Sedimentology and Stratigraphy**

- Professor Mary Kraus will be assisted by STF Bair in this class. The goals are to (i) improve interactive engagement within the lectures (primarily with clickers), (ii) complete development of learning goals, (iii) align laboratory exercises, homework, and other assessments with learning goals, and (iv) assess the effectiveness of the implemented interactive strategies.

## **6. GEOL 4474/5474- Vertebrate Paleontology**

- STF Bair will advise Professor Jaelyn Eberle as she implements SEI objectives in this specialty class.

## **7. Teaching Assistant Summer Training Workshop**

- The 1.5 day TA training workshop will be presented by STF Vredevoogd to all new Departmental teaching assistants in August 2010. To insure long-term sustainability, Professor Budd will be a co-instructor in 2010 and plan on taking over this workshop when the SEI program expires.

## **8. SEI course archive**

- Improve the organization and retrieval of teaching and assessment materials now uploaded to the SEI archive site. Organize along consensus learning goals. Improve faculty appreciation and use of the archival resource.

- Add new material and/or update material for Physical Geology (GEOL 1010), Earth History (GEOL 1020), Environmental Geology (GEOL 2100), Oceanography (3070), Mineralogy (GEOL 3010), Structural Geology (3120), Paleobiology (3410), Sedimentology and Stratigraphy (3430), and Fluid Earth 3820.

## **9. STF research projects**

- STF Bair plans to complete and write up a literature review on student misconceptions related to physical geology concepts, and (2) develop a web module on teaching students to read scientific papers for the NSF-sponsored Science Education Research Center (<http://SERC.Carleton.edu>).
- STF Arthurs will prepare manuscripts related to (1) the data collected on use of clicker technology to achieve learning goals in oceanography, and (2) unique aspects of TA training for the Geological Sciences as related to the teaching objectives of the SEI.
- STF Vredevoogd will initiate a new research project exploring value of in class activities/recitations in Earth History vs. a reformed but still lecture dominated class.

## 10. STF professional development

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

## Publications

**Arthurs, L.**, and A. Templeton, 2009, 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*, v. 57, p. 357-372.

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

**Arthurs, L.**, and T. Marchitto, (accepted pending revisions), “A qualitative methods approach to developing an introductory oceanography concept inventory survey”, *in*, GSA Special Papers: Qualitative Inquiry in Geoscience Education Research.

**Bair, A.R.**, (in review), How ‘clicker’ technology affects students’ voting behavior and attitudes: *Journal of Research in Science Education*.

D. Duncan and **L. Arthurs**, (in review), How do students respond to simple ways of improving student attitudes about science?: *Astronomy Education Review*.

**Bair, A.**, and R. Flowers, (in final preparation), Helping undergraduate students gain proficiency in critical analysis using primary science literature, and its impact on student views of the nature of scientific knowledge: for Journal of College Science Teaching.

**ABSTRACTS & PRESENTATIONS AT PROFESSIONAL MEETINGS:**

**Arthurs, L.**, and D. Budd, 2009, CU's Dept of Geological Sciences – Science Education Initiative Project (GEOL-SEI): A five-year plan to introduce and support an evidence-based and scientific approach to teaching: American Geophysical Union (abstract and oral presentation).

**Arthurs, L.**, and D. Duncan, 2009, The Role of Metacognition in Learning and Strategies for Developing Student Metacognition: Geological Society of America Abstracts with Programs. 41(7).

Bair, A., and R. Flowers, 2009, Teaching the nature of scientific (and geologic) knowledge through a “critical thinking” course on geologic time: Geological Society of America Abstracts with Programs. 41(7):251.

D. Duncan and **L. Arthurs**, 2009, “Does taking an introductory astronomy course increase student understanding of the Nature of Science?”, American Astronomical Society (abstract and poster).

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

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

#### 1. People

- a. Faculty Director: Dale Mood (May 2006-Aug. 2008), Bill Byrnes (August 2008-present)
- b. STFs: Francoise Benay, Teresa Foley, Katharine Semsar

#### 2. Departmental structures

- a. There is a Curriculum Committee that looks at the curricula of courses in the department, and if needed, offers suggestions or comes up with alternatives for what is currently in place.
- b. Since the department has been involved with the SEI, the IPHY department has been working to restructure the degree requirements for the IPHY undergraduate major.
- c. This year our focus has been on faculty development and upper-division course development. We have six (in 2010 seven) upper-division core courses. To graduate a student must take three of six upon completion of pre-requisites.

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

#### **1. *IPHY 2800: Statistics***

**Status:** active involvement

This course has three faculty members who rotate teaching. The Fall 2009 semester has a steady faculty member, and the spring rotates between two faculty depending on the semester. This course serviced approx 265 students in 2009.

##### **a. Learning goal development**

- i. The STFs have worked with the faculty members to help develop a final draft of learning goals for the Statistics course. This document will be submitted in 2010 to the teaching committee for final approval and use by the department.
- b. Faculty involved: Marisa Ehringer, Steve Hobbs

#### **2. *IPHY 3470: Human Physiology I***

**Status:** moved from active involvement to consulting

A total of 298 students were served in 2009. Two faculty members were involved in this course. During the spring semester, there were 2 TAs involved with the course, and 2 TA's were involved during the fall semester.

##### **a. Current Status**



- i. This course now has SEI support at the status of consultants. Faculty continue to use learning goals, clickers, homework assignments, pre-post tool and actively share materials among one another.
- b. Refining an assessment tool**
  - i. The assessment tool for this course has been revamped and focuses on misconceptions students carry in this course. The post test was revamped summer and fall 2009 and faculty validation began in Dec 2009. It was given in the course as a post-test and the score for this was 68%.
- c. Faculty resources**
  - i. An electronic binder is being maintained in the main office to be used as a tool for future instructors. This binder includes: primary physiology education literature, learning goals, potential clicker questions, identified misconceptions, level of knowledge with which students are entering the course, worksheets/activities for peer help sessions, homework, surveys, assessment tool, and quiz questions.
  - ii. Faculty have been sharing clicker questions, assessments, and lecture slides with new faculty.

#### **Recent Additions**

- d. Course Project

This project will expose students first hand to clinical research and tie into lecture through clicker questions and assignments that are directly associated with concepts taught in class.

- e. Faculty Involved in addition to SEI: Dr. Kenneth Wright, Dr. Janet Casagrand, Dr. Steve Hobbs

### **3. *IPHY 3410: Human Anatomy***

**Status:** moved from active involvement to consulting

In the 2009 academic year, there were a total of 662 students served. Two faculty members were involved with this course. A ½ appointed TA was involved with this course during the fall 2009 semester.

- a. Current Status**

This course now has SEI support at the status of consultants. Faculty continue to use learning goals, clickers, weekly homework assignments, pre-post tool and the biology CLASS.

**b. Developing an assessment tool**

- i. The assessment tool is in its final validation. The revised assessment tool now includes X questions. Interviews and validation of the assessment tool are taking place, and is currently administered the first and last week of the course.

**c. Sustainable resources for faculty**

- i. An electronic binder has been developed to be used as a tool for 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.
- ii. Students' study habits and abilities to integrate material on their own were documented for faculty to use in requesting TAs for the class. Anatomy faculty wish to add either a recitation section (or homework helpline) or homework assignments to help guide students in how to integrate information in the course, as well as add grading support to allow them to ask open-ended exam questions. They hope to use this documentation of students' difficulties in integration as support for these additional course resources.

**d. Faculty Involvement in addition to SEI:** Dr. Christopher Lowry, Ruth Heisler, Leif Saul

**4. *IPHY 3480: Human Physiology II***

**Status:** active involvement

In the 2009 academic year, there were a total of 220 students served. Three faculty members were involved with this course, two in a teaching role and one in an observational role. 1 TA was involved with this course in Spring 2009, and 3 in Fall 2009.

**a. Learning goal development**

- i. The STFs have worked with the faculty members to help develop a final draft of learning goals for the PHYS II course. These goals are aligned with pages and figures in the text. This document will be submitted in 2010 to the teaching committee for final approval and use by the department.

**b. 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 and in class activities (primarily concept maps) during class time.

**c. Class activities**

- i. Faculty have been routinely using the iClicker system. Both instructors have taken to developing their own clicker questions with minor feedback from the STFs. Various uses of clickers include regular reading quizzes, comprehension, and prediction from current and previous lectures.
- ii. In the fall semester, one class research project occurred. This project required the students to collect their own data over a period of time. This project was designed to give students exposure to clinical and field-testing, as well as to the data collection and analysis processes.
- iii. In the fall semester students began using concept maps as an active learning tool. The concept map activity occurred one time per unit with the goal to introduce students to the upcoming material and give them a global feel for the material. Clicker questions and in class discussion time are to be provided during the activity. Students reported a high level of academic value based on survey feedback but are looking for more interactive in class time with this project, which will be addressed in future semesters.

**d. Faculty Involved:** Dr. Cynthia Carey, Dr. William Byrnes, Heidi Bustamante

**5. *IPHY 3060- Cell Physiology***

**Status:** active involvement

One faculty member teaches the lecture and develops the lab. In Fall 2009 61 students were serviced by this course. One faculty member coordinates and teaches the lab section, which is integrated in the course. 3 TA's service this course. It is only taught in the fall.

**a. Learning goal development**

- i. The STFs have worked with the faculty member to help develop a final draft of learning goals for the Cell Physiology course. This document will be submitted in 2010 to the teaching committee for final approval and use by the department.

**b. 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. For Cell Physiology this course also had a focus on suggestions and clicker question development for future addition and use of clickers or homework for the students.

**c. Faculty Involved:** Dr. Dave Allen, Dr. Bob Hermanson

## 6. *IPHY 4720: Neurophysiology*

**Status:** active involvement

This course is taught by two faculty (one in the spring and one in the fall). In Fall 2009 this course serviced 88 students. 3 TA's assisted in the fall.

### **a. Learning goal development**

- i. The STFs have worked with the faculty members to help develop a final draft of learning goals for the Neurophysiology course. These goals are aligned with pages and figures in the text. This document will be submitted in 2010 to the teaching committee for final approval and use by the department.

### **b. 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 and in class activities during class time and help rooms (once a week).

### **c. Class activities:**

- i. Help Room
- ii. Clicker Questions
- iii. Homework

- d. **Faculty Involvement:** Dr. Roger Enoka, Dr. Janet Casagrand

## 7. *IPHY 4440: Endocrinology*

**Status:** active involvement

Two faculty teach this course (one spring and one in the fall), fall semester this course serviced 126 students. 3 TA's serviced this course in the Fall 2009.

### **a. Learning goal development**

- i. The STFs have worked with the faculty members to help develop a final draft of learning goals for the Endocrinology course.

### **b. 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 and in class activities during class time.

### **c. Class activities**

- i. In recitation, the students completed weekly concept maps and homework questions on the material covered in lecture.

## 8. *IPHY –Critical Thinking: Neurobiology of Disease*

**Status:** Has been moved to a heavy consultant role

One faculty member teaches this course. This course serviced approx 50 students over the 2009 academic year.

### **Learning Goal Development**

Goals were previously written by instructor. The goal being focused on is: Students should be able to identify and summarize the key parts of a primary literature article.

#### **a. Developing an Assessment Tool**

A new assessment tool has been developed for assessing experiment interpretation skills between classes taught with CPR and classes taught with multiple papers. The tool was loosely validated with three IPHY faculty that were not involved in designing the tool.

#### **b. Understanding Student Thinking and Misconceptions**

Examination of rubric responses in the peer review activities, final papers, and two mid-term and an end-of-term surveys has led to the conclusion that peer work is very beneficial for students to learn how to review primary literature and maintain positive attitudes during challenging coursework. We also concluded that we have no evidence that CPR was significantly helping students on key aspects of experiment/primary literature interpretation and thus are moving forward with a new strategy for Spring 2010. This new strategy will be compared with the CPR strategy through the use of a short assessment tool, referenced in (b).

#### **c. Class Activities**

STF help has guided the development and assessment of the introduction of Calibrated Peer Review into the course. We have assisted in the development of several other in-class activities.

## 9. *Other courses with some SEI IPHY involvement*

Due to interest generated by the department's involvement in the SEI, many courses have gone off this list and onto the full support list, but additional projects have been developed in the following course in the role of consultant.

#### **a. IPHY 3420 Human Nutrition and Performance**

- i. Use of clickers.
- ii. Weekly online homework assignments
- iii. Faculty: Owen Murphy

### **C. Other SEI activities**

1. Developed and Implemented Formal TA Training for Fall 2009 IPHY Graduate students.
2. Poster presentation at Experimental Biology Conference: Physiology Education section. Francoise Benay. Poster titled "*How Not To Lose Your Students in Concept Maps*."
3. Poster presentation at University of Colorado STEM Conference: Benay, Foley, Semsar, *Science Education Initiative in Integrative Physiology*
4. Panel Presentation at Experimental Biology, Katharine Semsar titled: *Bringing Scientists on Board: The CU Science Education Initiative, Helping Change the Way we Teach*
5. In review, manuscript entitled "*How Not To Lose your Students in Concept Maps*"
6. Development of a paper for publication. *CLASS (Colorado Learning Attitudes about Science Survey)* – a new tool to assess student beliefs about biology and learning biology.
7. Two members of the IPHY faculty complete a year study for the Presidents Teaching and Collaborative, Carnegie Foundation Program. STFs serve as coaches for these faculty. Dr. Casagrand focused her efforts on developing a rubric for faculty to Bloom their exams. This will allow faculty to track the change in assessment level each semester.

### **D. Goals for 2010**

1. Finalize learning goals for PHYS II, Neurophysiology, Endocrinology, Cell Physiology & Statistics.
2. Develop a Physiology II draft of an assessment tool.
3. Finalize the Anatomy & Physiology 1 assessment tool for publication.
4. Provide active learning support for upper-division courses.
5. Develop a system for sustainability of IPHY SEI.
6. Archive course materials for IPHY 3410, 3470, 3480.
7. Continue to support faculty efforts in upper-division courses.
8. Have the manuscript on "How Not to Lose Your Students in Concept Maps" be accepted upon upcoming re-submission after review.
9. Publish results of Calibrated Peer Review, Bloom's Rubric and Bio-CLASS study.

## VII. SEI in MCDB

### A. Departmental structure of the SEI program

Drs. Jia Shi and Michelle Smith are employed as Science Teaching Fellows. Dr. Jennifer Knight is the MCDB SEI coordinator, and Distinguished Professor Bill Wood is the MCDB Director for the program. A search for a third STF was conducted in late '09, and Dr. Sarah Wise was hired to begin work in January '10.

### B. Course-related efforts

#### i. 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.
- 2) Pre/post conceptual assessments that are either published (Smith et al) or in development.
- 3) Interactive learning such as use of in-class concept questions, small group activities, and/or co-seminar courses designed to give students a small group environment to practice solving problems.

We have also continued to publish our findings in peer reviewed journals. List of articles published or in press:

- i. Smith MK, Wood WB, Knight JK. The Genetics Concept Assessment: a new concept inventory for gauging student understanding of genetics. *CBE - Life Sci Educ.* 2008 Winter; 7(4):422. Also featured in the Best of 2008 print edition.
- ii. Smith, MK, Wood WB, Adams, WK, Wieman, C, Knight, J, Guild, N, and Su, TT. (2009) Why peer discussion improves student performance on in-class concept questions. *Science*, 323, 122-124.
- iii. Wood, WB (2009) Innovations in teaching undergraduate biology, and why we need them. *Ann. Rev. Cell & Devel. Biol.* 25, 93-112.
- iv. Knight, JK and Smith, MK. (2010). Different but equal? How non-majors and majors approach and learn genetics. *CBE Life Sci. Educ.* *in press*.
- v. Knight, JK (2010). Biology Concept Assessment Tools: Design and Use. *Microbiology Australia.* *in press*.
- vi. 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* *in press*.

We submitted two grants in 2009; an NIH Challenge Grant (12<sup>th</sup> percentile but unfortunately not funded) and an NSF CCLI Type 1 (still pending). Both grants proposed new ways to examine retention and the development of an assessment for our capstone majors courses. Tin Tin Su, Jenny Knight, Bill Wood, Michelle Smith and Jia Shi were co PIs.

## ii. *MCDB 1041 Fundamentals of Human Genetics*

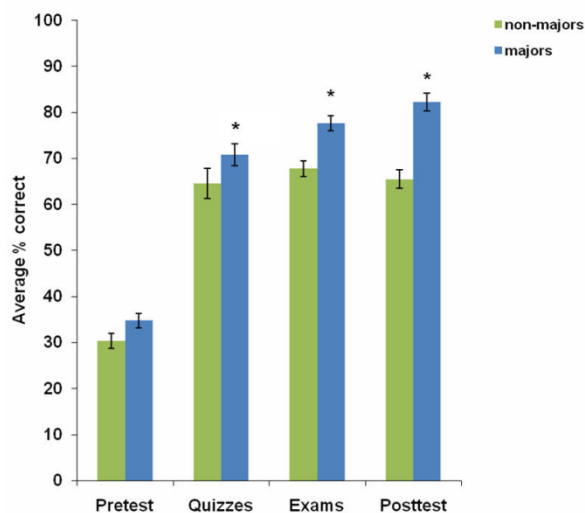
MCDB 1041 is offered every fall, taught by Dr. Jenny Knight. The typical enrollment is between 60-80 students. This is a course for non-majors that fulfills the Arts and Sciences distribution requirement for science. Michelle Smith has assisted with materials development for this course. This year, she was involved in data analysis for the research projects described below.

**b. Development of course materials.** Additional clicker questions were developed for a study of different pedagogical approaches on retention, described in more detail below.

### c. Research projects

*i. Different but equal? How non-majors and majors approach and learn genetics.* [The data for this project were collected in Fall 2008, but the analysis and preparation of the manuscript were done in 2009; the paper is in press.]

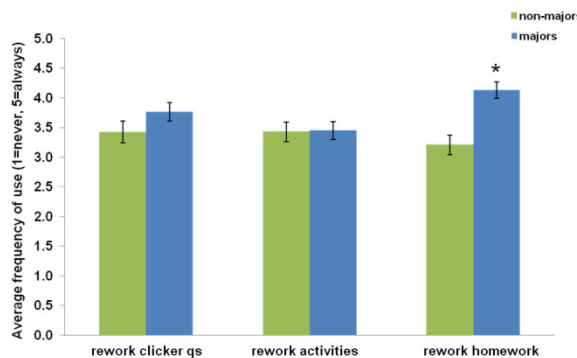
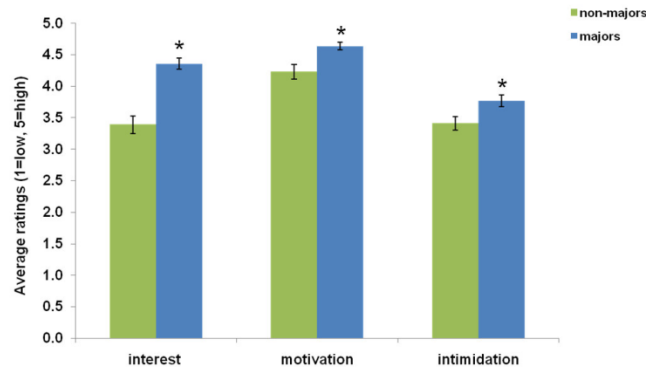
This study explored learning and attitude differences between students in a non-majors genetics class and a majors genetics class. To measure content learning, we administered identical questions to both sets of students at three different points in the semester: immediately after problem solving sessions, on in-class exams, and at the beginning and end of the semester (pre/post). Students in both the majors and non-majors classes make substantial learning gains, but the majors significantly outperform the non-majors. Notably, majors continue to improve their understanding on individual learning goals as the course progresses, while non-majors plateau (see figure below).



To measure attitudes, and their potential effects on learning, we administered three surveys (beginning, middle and end), in addition to the pre/post BioCLASS (Semsar et al, in preparation). Attitude and ways of studying appear to be the most likely influences on these performance differences. As shown in the figures below, majors



spend more time studying for exams, are more motivated and interested, and rework homework problems more frequently in their studying. In addition, their attitudes and beliefs about biology (as measured by the BioCLASS) are much more expert-like than those of non-majors (data not shown).



We concluded from this study that non-majors most likely need more emphasis on why they should learn genetics (real life applications) and more encouragement to “buy in” to the class. Even if this kind of approach did not improve their performance, it might better engage and motivate them, improving their attitude about science.

ii. Fall 2009: Follow-up study on what impacts the way in which non-majors learn genetics. Several changes were made to the non-majors genetics course in the hopes of addressing the findings described above.

- a. A “learner-centered” approach was adopted: students chose which assignments to do over the course of the semester (only the final exam and a group project were required), as well as choosing the last three topics of the course (final 1/3 of the semester).
- b. Students were given an opportunity to reflect on their learning process in 10 “learning logs” over the semester. In these learning logs, students were

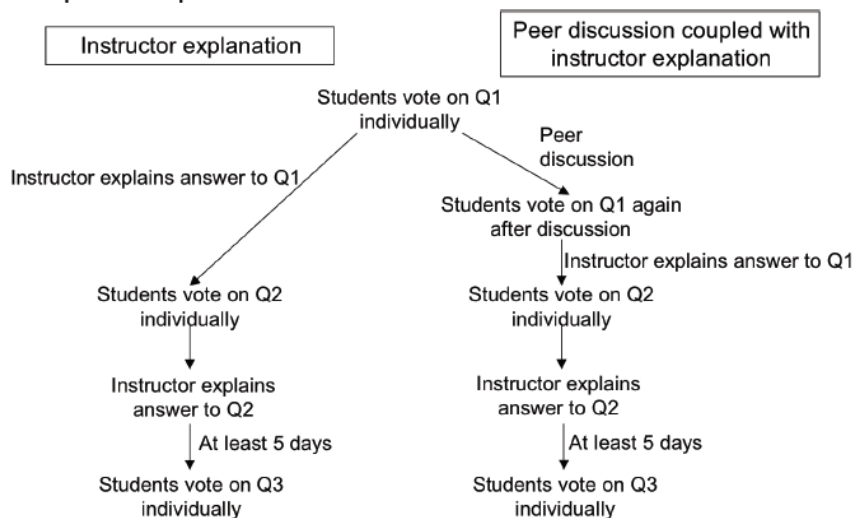
given a prompt such as: What is your study or learning strategy for this class right now? How will you change your study strategy now that you've taken the first quiz? Many of the responses demonstrate that students were grateful for a chance to reflect on the process of learning genetics. These logs may contain some important information about student attitudes, and will be carefully analyzed.

c. More emphasis and accountability was placed on group work: quizzes were taken individually and then retaken for a group grade, and the same group also worked together on a final group project presentation.

The same content assessment questions and attitude questions were asked in the Fall 2008 and Fall 2009 courses. In the upcoming year, we will be comparing the learning outcomes and attitudes of these two groups.

iii. What pedagogical techniques enhance retention of learned concepts within a course? We previously showed that peer discussion enhances understanding of in-class concept questions (Smith et al, 2009). Preliminary data from the majors genetics course (discussed below in more detail) indicated that students show increased understanding on in-class concept questions when peer discussion is 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 answered in-class concept questions after hearing an instructor explanation, or engaging in peer discussion and hearing an instructor explanation (see figure below). To measure retention, students were asked to answer in-class concept questions on the day they first are presented with material and then individually answer a very similar (isomorphic) in-class question two class periods later.

Experimental protocol to determine how much students retain from listening to an instructor explanation of an in-class concept questions versus coupling peer discussion with an instructor explanation.



Our preliminary analysis of these data suggest that the two methods do not produce significantly different levels of retention; in each pedagogical approach, the average score on the retention question (measured by percent of students answering Q3 correctly) is 65% for the combination approach and 63% for instructor only approach. This finding is particularly interesting because a similar level of retention has been found in different classes (see 2150 section below). These data will be fully analyzed in the upcoming semester.

### ***iii. MCDB 1150 Introduction to Cell and Molecular Biology***

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 has worked with this course since 2006.

#### **d. Development of an assessment instrument to measuring student learning**

Significant changes were made to the Introductory Biology pre/post concept assessment. Jia Shi conducted student interviews (n=10) during the summer 2009. Student feedback helped reworded new questions that include scientific jargon and provided better distracters for incorrect answers. A total of 25 introductory biology faculty from multiple institutions took the assessment and provided suggestions. Drs. Jia Shi, Jenny Knight, Jennifer Martin and Bill Wood rewrote the questions that were rated low in clarity by these faculty experts. In fall 2009, the updated assessment was given to students in MCDB 1150 as well as at another similar research university. This assessment has now gone through several rounds of testing and re-writing. A publication describing this work will be submitted early in 2010.

#### **e. Research studies: development of new clicker questions to measuring student learning and retention**

In fall 2009, Drs. Jennifer Martin, Nancy Guild and Jia Shi developed 100 new clicker questions that were used in a clicker study. The purpose of this clicker study was to examine if building concepts via three clicker questions (linked questions; answering each subsequent question depends on understanding the previous question) help student learn and retain concepts better than via three unlinked clicker questions (where the questions do not build on each other but still may be related). In both cases, the concept tested with the final clicker question of a class period (Q3) was then asked again as an isomorphic question (Q4) 7 days later. Isomorphic questions to Q4s were also asked in the final exam to measure student learning over the course of the semester. Results are currently being analyzed.

### ***iv. MCDB 1152 Intro Coseminar***

Dr. Nancy Guild is now officially in charge of the MCDB 1152 course (the co-seminar associated with 1150). 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). In Fall 2009, 129 students (about 1/3 of students from MCDB 1150) enrolled in MCDB 1152. Dr. Guild met with five undergraduate learning assistants weekly to prepare them before leading the co-seminar sessions. At the end of every activity, students took quizzes to help us monitor learning. Students rated the co-seminar highly

on FCQs and felt that it helped them better understand the material in the lecture portion of the course.

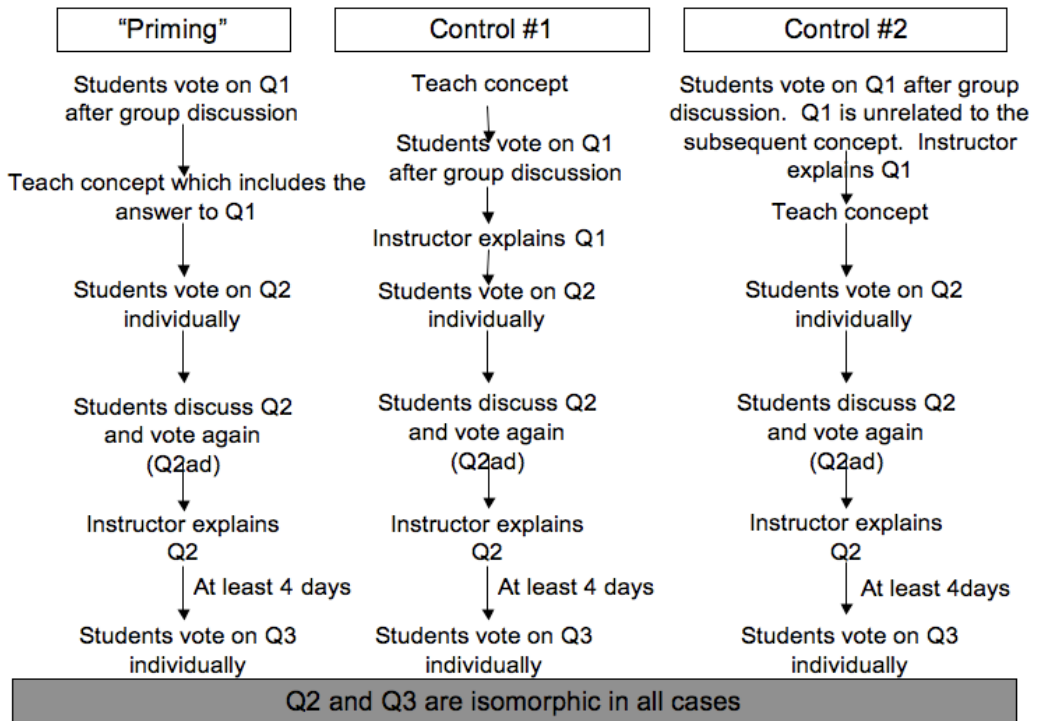
v. ***MCDB 2150 Principles of Genetics***

Principles of Genetics follows MCDB1150 and is offered every fall and spring. The typical enrollment is approximately 150 students in the fall and approximately 400 students in the spring. Dr. Mark Winey taught the class in Spring '09, and Dr Tin Tin Su taught the class in Fall '09. Michelle Smith has worked with faculty in this course since Spring '07; this year, she worked only with Tin Tin Su in the fall semester '09.

- f. Developing course materials. Additional clicker questions were written in the Fall 2009 semester for the research project described below.
- g. Comparing the effects of different in-class pedagogical techniques on learning (data collected during the fall 2008 semester taught by Ken Krauter and analyzed during 2009)

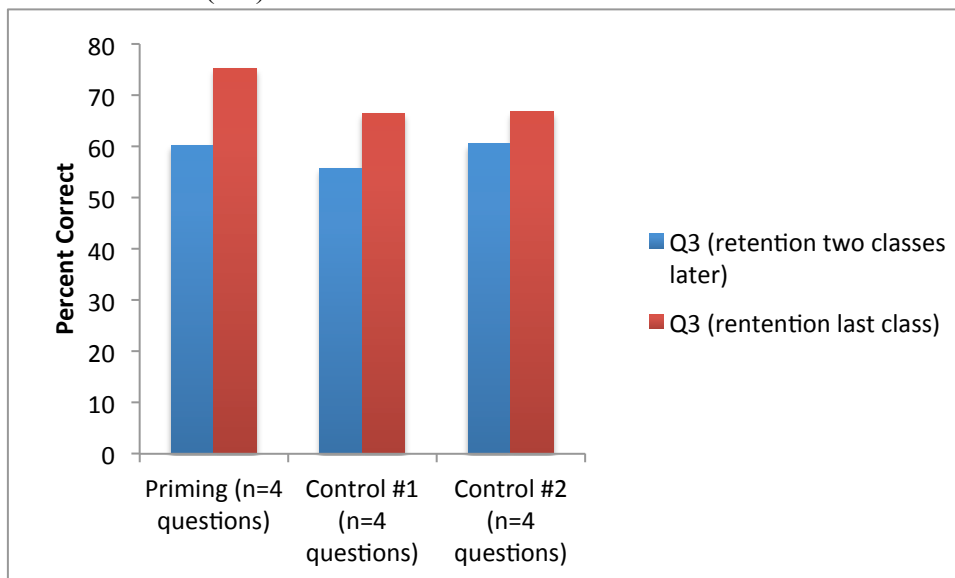
To determine best practices for maximizing student learning from in-class concept questions, pairs of isomorphic (very similar) clicker questions were used to monitor student understanding in the majors genetics course. After answering the first question individually, students either participated in peer discussion, listened to an instructor explanation, or both, before answering the second question individually. Our preliminary results show that the combination of peer discussion followed by instructor explanation significantly improves student understanding when compared to either approach alone. The performance improvement is most pronounced for the more challenging questions and for students who in general have the most difficulty with in-class concept questions.

In the fall 2009 genetics course (taught by Dr. Tin Tin Su), we used a similar (isomorphic) clicker question protocol to measure how well students retained information when they were primed with questions at the beginning of a lecture. Our experimental design is described in the figure below.



Student performance on the Q3 retention question was similar for all three arms of the protocol (Blue bars below). However, on the last day of the semester we re-asked the retention questions again, and found that students performed better on the questions that were presented with the “priming” protocol (Red bars below). We will continue to analyze these data in the coming year.

Student performance on Q3 two classes after material was presented (blue) and on the last class of the semester (red).



h. Developing resources for the faculty

The bank of questions (clicker, homework and exam) for genetics is updated each semester.

**vi. MCDB 2152 Genetics Coseminar**

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.

**vii. MCDB 3120 Cell Biology**

- i. **Development of course materials.** Cell Biology was offered both fall and spring semesters in 2009. The typical enrollment is approximately 200 students in the fall and approximately 120 students in the spring. Dr. Robert Poyton taught the class during the spring 09 semester and Drs. Greg Odorizzi and Gia Voeltz taught the course in fall 09. Dr. Jia Shi started working with this course in January 2008.

Last year, Jia worked with the faculty to develop learning goals and a draft of a pre- and post-assessment, as well as in-class clicker questions and homework for the course.

All of these resources were used in spring 09.

In fall 09, the faculty decided not to use homework questions, but did use existing clicker questions, developed new questions, and gave the pre-post assessment.

- j. **Future plans.** This year, the faculty decided to change the way these two courses are offered. Beginning in fall 2010, the Cell and Molecular Biology courses will be integrated; they will be offered in sequence only as Cell and Molecular Biology I and II. It is not yet clear how the STFs will work with the faculty on this sequence.

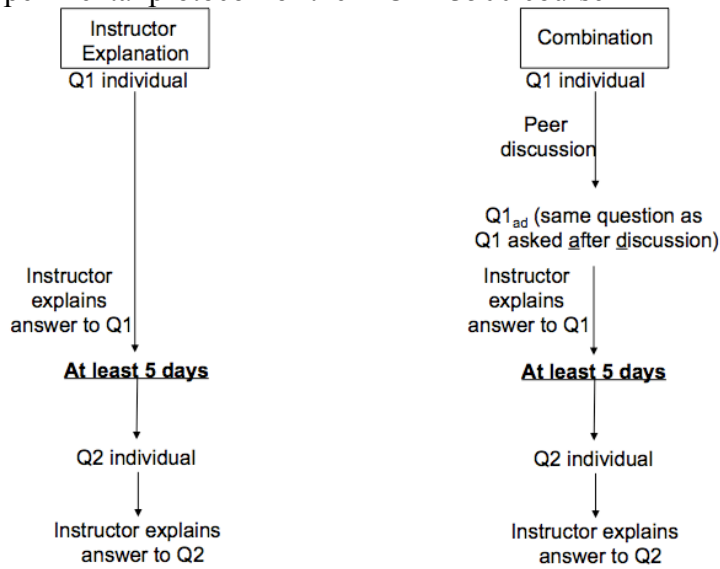
**viii. MCDB 3500 Molecular Biology**

Dr. Jens Lykke-Andersen taught this course during the spring 2009 semester and Michelle Smith worked with the course. Michelle and Jens wrote a pre/post molecular assessment that was given at the beginning and end of the course. A revised version of the assessment is being given to the spring 2010 molecular course.

During the spring 2009 semester, homework was added to the course for the first time. On an end of year survey 90.1% of the students felt that the homework was useful for their learning.

Michelle and Jens also performed an experiment to examine student retention on in-class concept questions using a protocol that is similar to the one described above for the non-majors genetics course (figure below). We found that student performance on the retention questions (Q2) was similar for both arms of the protocol (56.4% for the instructor explanation arm and 55.5% for the combination arm).

## Experimental protocol for the MCDB3500 course



### ix. MCDB 4300 Immunology

- k. **Course development.** Dr. Corrie Detweiler teaches Immunology, which is one of the capstone courses for the major (Developmental Biology is the other). Corrie had previously tried to integrate some active learning techniques into this course, and was very discouraged by her experience. Therefore, Michelle focused on helping Corrie integrate clicker questions, especially challenging ones, into each class period. She also worked with Corrie on quiz and exam questions. Michelle and Corrie developed a draft pre-post assessment that will likely be modified and incorporated into a future capstone assessment for all three capstone courses. The immunology students took an end of year survey and the responses were quite positive showing that students appreciated the active learning components of the course. For example, 89% of the students felt that answering clicker questions was useful for their learning.
- l. **Future plans.** Immunology will not be taught in 2010, but all questions from '09 will be archived, and we anticipate that Corrie will be able to continue to make progress in transforming this course. In the meantime, she will also participate in establishing common learning goals and an assessment for all capstone courses.

### C. Faculty Presentations.

Bill and Jenny offered the Teaching and Learning Seminar (MCDB 5650) in spring '09. There were 16 participants in the class, including undergraduates, graduate students, and postdocs from five different departments.

Bill presented the work of the SEI at the AAAS symposium *Vision and Change: Transforming Undergraduate Biology Education* in summer 09. He also presented talks on the SEI, the development of the GCA, the study on peer discussion, and the general need for change in undergraduate science teaching in talks at the National Academies Summer Institute for Undergraduate Education in Biology and the annual meeting of the Society for

Developmental Biology in addition to seminars at several universities, including Ohio State, Utah State, U. Toronto, and U. of Hyderabad, India (via internet). He also published a *Science Education Forum* article: Revising the AP Biology Curriculum (25 Sept., 325, 1627-8).

Jenny participated in the Biology Scholars Program, a competitive research residency program sponsored by the American Society for Microbiology. This year-long program began in the summer of 2008 with a week-long workshop, and culminated at the ASM Conference for Undergraduate Educators in May 2009. Jenny presented a poster on the majors vs. non-majors genetics study, as well as a talk on using the Genetics Concept Assessment to inform teaching. Jenny returned as a facilitator for this program (helping other faculty develop education research questions) in Summer 2009.

#### **D. Goals for 2010**

- i. General:
  - a. The SEI group will be working on writing and submitting at least three papers in the next year.
  - b. The MCDB team will meet every other week in a lab-meeting type format.
- ii. Assignments for Jia Shi in 2010
  - c. Finalize papers (group work in Intro; Intro concept assessment)
  - d. Work with Joy Power in the Cell Biology Lab course. This is a slight change in focus, as we have not yet addressed needs that might exist in the lab courses. We are beginning with Cell Biology because Joy is enthusiastic about change, and already embraces the idea of inquiry-based labs. Currently Jia and Joy are developing a pre-post test on using controls in experimental design, as well as designing activities that will be incorporated into the lab environment to help cement student learning on this topic.
  - e. Work to establish common learning goals for all capstone courses and work on developing a capstone concept assessment for the MCDB major.
- iii. Assignments for Michelle Smith in 2010
  - f. Work with Michael Stowell on Molecular Biology. A draft pre-post assessment has been developed and work will continue on its development. Dr. Stowell is also interested in the effect of homework on student learning; therefore, students will be asked in class clicker questions on concepts that are either covered or not covered on the homework, and then asked isomorphic questions after homework has been submitted. We anticipate that the student performance on clicker questions that were also addressed by homework will be better than those not addressed in the homework. If we can demonstrate this, future faculty may be more likely to assign homework in Molecular and Cell Biology.
  - g. Retention studies. Michelle will coordinate an effort to extract trends and draw conclusions from the multiple related clicker studies completed in the last year in several different classes.
  - h. Work with Jenny Knight on possible research questions in MCDB 4650, Developmental Biology.
  - i. Work to establish common learning goals for all capstone courses and work on developing a capstone concept assessment for the MCDB major.
- iv. Assignments for Sarah Wise in 2010



- j. Work with Kevin Jones on transforming the Molecular Neurobiology course into a capstone course. Sarah is helping Kevin to establish learning goals and write clicker questions. She will also observe each class period, collecting student misconceptions, student ideas, and will begin to develop additional interactive tools for future use.
  - k. Work to establish common learning goals for all capstone courses and work on developing a capstone concept assessment for the MCDB major.
  - l. Work with the Intro lab course to establish what is currently done well, and what can be improved.
5. At least one of the STFs will work with faculty on the new combined Cell and Molecular Biology course in fall and spring 2010.

## 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 more recent work in outreach (see section II "SEI Central Activities"). Dr. Steve Goldhaber started Summer 2008, and has focused on Quantum Mechanics 1 (PHYS 3220). Dr. Rachel Pepper started in Summer 2009 and has been continuing Dr. Chasteen's work in PHYS3310 and is beginning work in Mechanics and Mathematical Methods (PHYS2210). Paul Beale serves as Departmental Director of the SEI efforts.

Two faculty working groups have formed focusing on the two upper-division courses that are the focus of the SEI (PHYS3310 – Electricity and Magnetism 1 and PHYS 3220 – Quantum Mechanics 1). The feedback of these groups of faculty has provided crucial direction for the STFs. A third working group will be formed in the 2010 academic year, facilitated by Dr. Rachel Pepper, to focus on Mechanics and Mathematical Methods.

### 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, and Schibli in Fall 2009. 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. For future iterations, DeWolfe has indicated that he will use, at the very least, the clicker questions and tutorials developed for the course.

### **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 and promoted at the AAPT and PERC meetings and met with considerable interest. A total of 53 faculty have indicated an interest in using the materials, and to date we know of at least 10 who have done so. This enthusiastic response to our materials is a strong indicator of the need within the physics community for research-based materials for teaching upper-division E&M. We developed a preliminary survey of users of the materials, which indicates that most instructors became aware of our materials through research conferences and publications, though we are also aware of some who have located our work through internet search engines that directed them to our website. That survey suggests that most users are new instructors, seeking pedagogical guidance. Thus, these materials represent a valuable opportunity to impact the next generation of college instructors such that they develop interactive teaching strategies based on research.

Another important aspect to disseminating and sustaining the course transformations is providing an organizational structure that is easily navigated and lends itself to a-la carte use of individual resources, so that instructors may tailor their use of the materials to their

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

particular class and teaching style. Overall reactions to the organization of the materials – by instructors at CU and outside -- was positive.

The four 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. These interviews will be the subject of future analysis, but key results are described below in the faculty impact section.

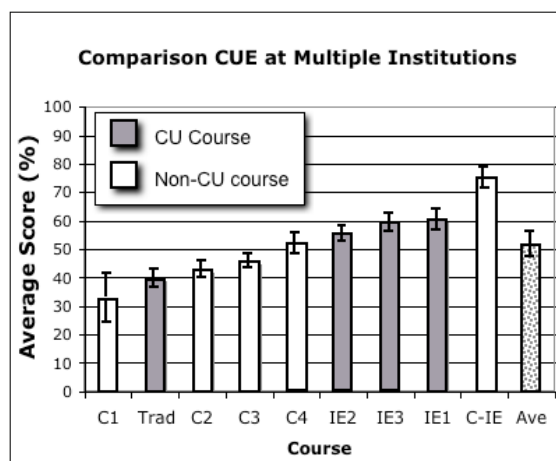
### **c. Colorado Upper-Division Electrostatics (CUE) Assessment**

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 5 semesters of E&M I students – Fall 2007 (taught traditionally), Spring 2008 (the first semester of transformations), Fall 2008, Spring 2009, and Fall 2009 (successive iterations of transformations), although results from Fall 2009 have not been analyzed at the time of this report. The CUE post-test was also given in seven courses in five outside institutions. All courses with CUE scores above the mean used interactive engagement techniques, such as clickers – this provides some of the first evidence that interactive engagement techniques improve student learning, even at the upper division. At CU, students in the first three iterations of the transformed course performed better on the CUE than those in traditionally taught courses at CU and elsewhere (significant except for one set of courses).



**FIGURE 4.** Courses C1-4 and C-IE are non-CU. “Trad” is a traditional lecture-taught course, and IE1-3 used similar research-based course transformations.

The CUE pre-test was given to 1 semester of E&M I students at CU (Fall 2008), as well as three outside institutions and a group of students at CU who had just completed the introductory E&M course. 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 5 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 five courses are in progress. For the first iteration (Fall 2007 versus Spring 2008) students in the transformed course outperformed those in the traditional course on a variety of measures:

- Attendance in lecture (75% in traditional, 90% in transformed)
- Attendance in optional recitations (29% in traditional, 65% in transformed)
- Reported time on homework (18% spent more than 6 hours/week in traditional, versus 90% in transformed)
- Traditional exam problems (students in transformed course performed significantly better than those in traditional course on 5 common problems)
- CUE (43% in traditional course, 61% in transformed)

Preliminary analyses suggest that these results hold overall, but to a somewhat lesser degree, in later iterations of the transformations. Thus, the positive impact of the transformations extends beyond the course taught by the curriculum developer. The

<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.

reason for the reduced efficacy of the course materials in later iterations is of significant interest to the field.

The Basic Electricity and Magnetism Assessment (BEMA) has been given to students at the end of introductory (freshman) E&M for 10 semesters and at the end of 3310 for 7 semesters. Students in PHYS 3310 in Fall 2008 were also given the BEMA as a pre-test. This tool assesses student understanding of concepts in electricity and magnetism at the freshman/sophomore level. Students in two out of three transformed courses studied experienced small positive shifts in BEMA scores after PHYS 3310, as compared to their freshman scores. When BEMA scores are examined by subtopic, students do score better on some groups of questions related to topics specifically addressed by PHYS 3310. Thus, the transformed upper division courses have, at best, only a small impact on student conceptual understanding at the freshman level. Conceptual understanding does not naturally improve in an interactive course – concepts must be explicitly targeted in order to address student difficulties with that material.

Students in PHYS 3310 were also asked to complete an attitudinal survey regarding the course, including questions about their homework and study habits, and whether they thought the content in the course was relevant and interesting. Similar questions were given across all three semesters, as well as in upper-division courses other than 3310. This work is ongoing and analyses are incomplete, though attitudes look generally positive in both the traditional and transformed courses. Most student responses in Spring 2008 focused on the quality of the instructor, homeworks, and extra help sessions.

There was a strong sense of student enthusiasm in the first iteration of the transformed course that was not as strong in successive iterations – reflected as well in decreased attendance in successive iterations. The student body in the first transformed course appeared to be slightly better prepared than other classes in the study (as measured by Physics GPA). That course was offered in the spring which – as previously mentioned – is both a smaller course and comprised of more physics majors than the fall courses. The second iteration of the course transformations (Fall 2008) appears to have been the least successful, both as measured by lower CUE results and by student opinions on the end-of-term course questionnaire administered by the university. These effects are under investigation, as well as other data on differences between successive iterations, to assess sustainability of the transformations.

#### **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.

Graduates were employed in a wide variety of jobs, especially in industry and finance. Fewer continued on to graduate school than had been expected, with a total of 35% never having attended graduate school. Many recurrent themes were noted with respect to upper-division E&M and Quantum, such as an appreciation of the intellectual challenge of the course, but a dissatisfaction with the focus on mathematics at the expense of conceptual understanding, and a disconnect from real-world examples. Alumni who continued on to graduate school found the material of both E&M and

Quantum to be more relevant to their careers and lives. These results provided useful information about our graduates and how we might serve their needs through these course transformations. In particular, the following questions were posed to the undergraduate committee, based on these results: (1) Are we meeting the needs of those who do not attend graduate school? (2) Are we focused appropriately on problem-solving and critical thinking? (3) How do we increase continuity in two-semester courses? (4) How can we support supplemental activities from instructors? And (5) Can and should we increase the conceptual focus in upper-division?

### **3. *Quantum Mechanics I (PHYS 3220)***

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

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

Activities in Quantum I include:

#### **a. The Quantum Mechanics Assessment Tool (QMAT)**

With the assistance of several faculty members, Steve Goldhaber has developed a post-test assessment tool based on learning goals, and has performed preliminary validation of the instrument through interviews with faculty and students. During development of the test, a total of 21 students were videotaped while they took versions of the test and explained their reasoning out loud. A total of 27 students took the test as an in-class diagnostic exam near the end of the Fall 2008 semester. As an incentive to take the test seriously, students were offered individual feedback on their strengths and weaknesses in areas such as quantum mechanics formalism and separation of variables. The test was revised and administered in both the Spring 2009 and Fall 2009 semesters. In all, a total of 89 CU quantum I students have taken the assessment. In addition, near the end of the Fall 2009 semester, the QMAT was administered at four outside institutions to a total of 113 students.

This instrument will not serve as a pre-test, since most students have not previously been exposed to much of the content of the course.



## **b. Course Materials**

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

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

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

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

### **1. E&MI (PHYS 3310) working group**

The faculty working group for E&MI was convened twice this year, to present results from the alumni survey and the course transformations. The results of the alumni survey were also presented at the faculty meeting at large, and distributed to every faculty member. Some members of the faculty working group for 3310 were consulted individually as the CUE post-test was revised.

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

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

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

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

### **2. Quantum Mechanics I (PHYS 3220) working group**

The faculty working group for quantum mechanics I meet 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. 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 2010**

##### General:

- Encourage conversation between physics and math faculty regarding preparation of students for upper division physics courses
- Investigate actual instruction in classical mechanics and mathematics received by CU physics majors in their first 2½ years. This information will help enumeration of realistic pre-requisite skills for students entering PHYS 3220 and PHYS 3310.

##### 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 2210:

- Obtain wide faculty agreement on learning goals for mathematical methods and classical mechanics for the combined 2210, 3210 sequence at both course scale and subject scale.
- Create and administer an intermediate mechanics/mathematical methods conceptual post-assessment tool similar to the CUE and QMAT.
- Investigate student difficulties through weekly homework help sessions, individual student interviews, and small-group student interviews.
- Create a bank of homework, exam, and clicker questions.
- Modify and create weekly tutorials.