

2008 Annual Report
for the
CU Science Education Initiative

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2008 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:

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

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

As the SEI approaches the end of its 3rd year, the departments and faculty participating in the SEI have indeed changed substantially.

a. Impact on Faculty

In three of the four initial departments that were selected for SEI support three years ago, 60% or more of the faculty teaching undergraduate courses have changed their teaching practices to be more aligned with what research has shown to be effective. This impacts the instruction of 80% of the student credits taught by those departments. Across the entire project, over 100 faculty in 5 departments (CHEM, GEOL, IPHY, MCDB, PHYS) have been impacted by the SEI with 74 having modified their teaching.

Since the SEI began, 56 faculty have started interspersing conceptual questions in class and using clicker technology to engage *all* students in actively thinking about and discussing the material. In addition, many of the faculty who were already using clickers have improved the pedagogy of their use. Over 50 faculty have incorporated other interactive engagement methods in class – typically some form of small group activities either in lecture or recitation.

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

By the faculties own account, the project has changed departmental culture. Discussions about teaching, learning, and departmental courses are much more frequent among the faculty and are now integrated into formal departmental structures such as faculty meetings.

b. Impact on Students

After 3 years, the SEI project has impacted 53 of the undergraduate courses in these 5 departments, with the STFs working very closely with faculty on 25 of these courses. There are 20 courses with explicit learning goals developed by faculty consensus and another 19 courses where individual faculty have created such goals. Explicit learning goals that define what students should be able to do after taking a course benefit the faculty and departments, and the students have expressed in surveys how helpful they find the explicit goals.

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

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

c. Establishing CU as a leader in STEM education

The SEI project is now attracting national attention as a leading effort in science education reform. Wieman has given over 20 invited talks highlighting the CU and UBC SEI efforts. In Summer 2008, Wieman was selected as a keynote speaker for the Facilitating Change in Undergrad STEM Conference, recognizing the progress that is being made at University of Colorado in this regard. In addition, the department-based STFs regularly give presentations at national meetings within their disciplines, and are being recognized for advancing the college-level science education work in these disciplines. Several STFs have been asked to serve as advisors on national boards or projects examining education related issues in their discipline.

The SEI project is also gaining recognition through a number of peer-reviewed publications. With a paper in *Science* magazine, Tin Tin Su (MCDB faculty), Michelle Smith (STF), Wendy Adams (SEI Central), and others received widespread national attention for establishing the importance of the pedagogical approach when using clickers. The SEI project has also generated several teacher guides on various research-based teaching practices. The SEI *Clicker Resource Guide: An instructor's guide to the effective use of personal response systems ("clickers") in teaching* is fast becoming a staple in training teachers on effective use of clickers, and is now being disseminated by i-Clicker. A new video highlighting the pedagogical benefits of clickers and capturing the enthusiasm of faculty and student users at CU has just been completed, and is expected to have a significant impact in the higher education community.

I. Overview of Science Education Initiative

The CU Science Education Initiative is designed to implement and coordinate departmental-wide improvement of undergraduate science education. The major goal of the SEI is to bring about the transformation of the teaching of science on a sustainable department-wide basis to research-based methods that have been shown by CU-Boulder faculty to be highly effective in achieving their 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) determining 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 2008, faculty involvement in the SEI, and departmental goals for 2009.

II. Central SEI Activities

A. Update on central staffing

Carl Wieman continues to actively direct the CU Science Education Initiative together with associate director, Kathy Perkins. While Carl splits his time between CU and University of British Columbia (UBC), he generally travels to Boulder for several days each month and is in active email contact. In addition, Carl continues to establish collaborations between the CU and UBC SEI efforts where beneficial.

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

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 now stabilized. 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, 2 new STFs have been hired (one in Physics 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. Structural and operational changes

In Summer 2008, several changes were made in response to an internal SEI project management evaluation completed by the 12 STFs. These included: 1) a formal shift towards more departmental independence within the project, recognizing that the department STFs were now well versed in research on teaching and learning and that the faculty themselves were more knowledgeable about education research and needed less oversight from SEI central; 2) a renaming of departmental faculty liaisons to the SEI to departmental SEI directors reflecting this shift; 3) faculty meetings in 3 of the 5 departments to highlight this shift and spur productive discussions among the faculty with evidence of faculty assuming more ownership of the project; and 4) a reduction in formal STF training meetings to once per month, although SEI central personnel still serve as a well-used resource for individual STFs on a wide variety of topics.

D. Activities to support departmental-based efforts

The SEI central staff (Carl Wieman, Kathy Perkins, Wendy Adams, 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 monthly 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 2007, Wieman and Perkins hosted the third 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. Approximately 50 people attended, including about 25 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. In addition, SEI invited Dan Schwartz (Stanford) to CU-Boulder and as part of his visit he gave a workshop on how create and assess invention activities for STFs and faculty, about 25 people attended the workshop.
9. The SEI is co- funding work on several new interactive simulations, to be completed in the subject areas of biology and geosciences. This effort is in collaboration with CU’s PhET project – an award winning program to create highly effective interactive simulations for learning science. In addition the PhET project has been developing simulations in chemistry. In the past year, simulations have been completed on Glaciers, Eating and Exercise, and pH scale. Currently, work is being done on a natural selection simulation, a genetics simulation, and an acid-base simulation. The goal is that these simulations will aid the departments in their efforts by providing a resource to be used in courses within the department.
10. Adams provides departmental support and communicates pertinent information related to expenses, hiring, and budgeting.
11. Frankel manages 2 undergraduate students (20 hours per week) who provide support services to the STFs, primarily posting and processing online student surveys.

E. 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.

In 2008, speakers included: Dan Schwartz (Educational Psychology and Science Education): “Transfer of Learning”; Melanie Cooper (Chemistry Education Research) “Assessment & Improvement of Problem Solving”; Dee Silverthorne (Integrative Physiology) “Adapting to the Interactive Classroom from Student and Faculty Perspectives”; and Joe Redish (Physics Education Research) “Rethinking Physics for Biology Students”.

2. Workshops/Brownbags

SEI Central hosted a faculty workshop with invited speaker Dan Schwartz (Educational Psychology and Science Education) where faculty and STFs learned about and practiced creating “invention activities”. Invention activities present students with several contrasting cases and ask them to “invent” some rubric, mechanism, design, rules, etc. that explain these cases. By taking part in this type of activity before formally studying a subject area, students begin to recognize the underlying structure of the knowledge necessary and in doing so are more prepared to learn the formal answers. Several faculty have tried invention activities in their classes as a result.

The SEI Geological Sciences team ran a series of 5 workshops over the courses of the Fall 2008 term, covering a series of topics including: 1) Student misconceptions in geology, 2) Content interactions and student thinking, 3) Maintaining student interest & enhancing learning, 4) Classroom demos, and 5) SEI-GEOL’s future.

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. For example, in Geosciences, an environmental working group was started to design a new environmental majors track within the department and to develop the foundational course for that track.

3. Teacher guides and short videos

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:

“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.

The “Clicker Resource Guide” has received a lot of acclaim in the community and can be found on iClicker’s website.

In addition, the CU and UBC SEI projects are co-investing in the creation of a series of short videos which highlight various pedagogically-effective teaching practices. Our hope is that these videos will achieve some of what written text cannot by providing faculty with a model of what effective implementation of these practices actually looks like in the classroom. The videos also allow a mechanism for practicing faculty to “talk” to their peers and convey their enthusiasm about these new approaches to teaching – appealing to the emotional side of potential-adopters. The first of these videos is now complete and can be found by following the link: <http://STEMclickers.colorado.edu>.

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 workshop, and course-related resources. UBC SEI is primarily responsible for compiling these resources and our websites are linked to direct faculty and visitors to that resources base. These resources are expanding as the SEI work progresses both at CU and UBC. The website can be found at: <http://www.colorado.edu/sei/>.

In addition, the CU SEI effort is collaborating 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 is in place and is being piloted by SEI STFs.

F. Advisory board input

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

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

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

III. Highlights from the SEI Project

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

A. Impact on Faculty, Courses, and Departments

The SEI project has involved a significant percentage of the faculty teaching undergraduate courses within the 4 departments initially funded. Figure 1 shows the percentage of faculty who have made either significant or casual use of the SEI STFs and other SEI resources in their work to improve their courses. In the Geological Sciences department, a remarkable 97% of the faculty who teach undergraduate courses have made use of SEI resources. Due to the Physics department's long-standing involvement in education research and reform, the percentage of teaching faculty previously involved in education reform and in implementing research-based teaching practices was large to begin with and so is not reported here. The SEI efforts within Physics have been focusing on the upper-division courses which had not yet been transformed.

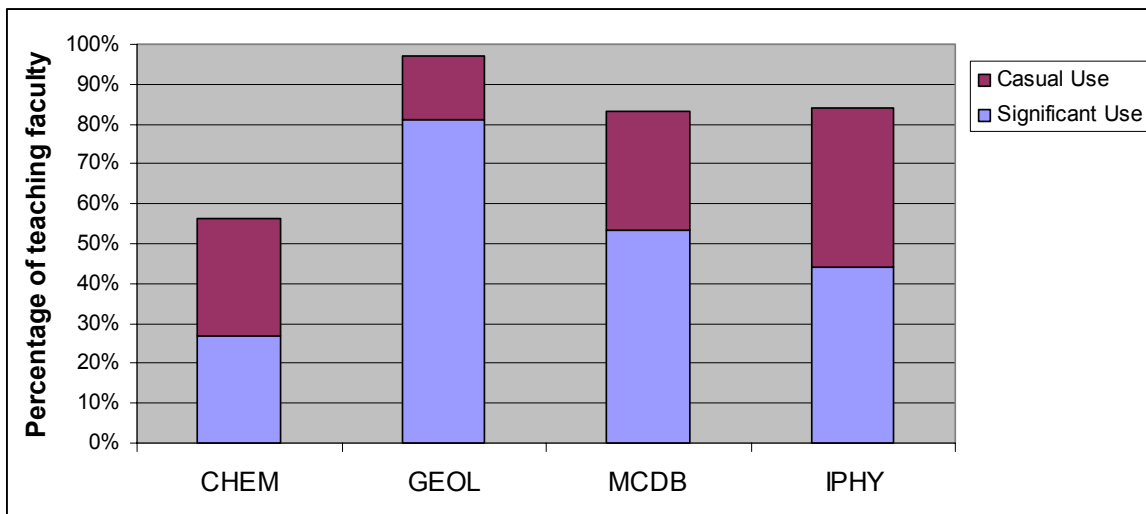


Figure 1: Use of SEI resources (e.g. STFs) by faculty teaching undergraduates.

The faculty's interactions with the SEI project have resulted in 74 faculty modifying some aspect of their teaching across 53 courses. In 22 courses, faculty have started interactively engaging students using conceptual questions and clickers. Optional or required recitations or co-seminars have been added to 8 courses to provide environments where students can engage in small-group activities requiring students to actively engage in sense-making and build their understanding of the main concepts. In addition, many existing recitations or labs have been restructured to incorporate this inquiry-based approach to learning as opposed to the less effective mode of TAs reviewing problems at the board. Homework assignments have been added to 19 courses (previously these courses had no homework), and existing homework in a number of courses has been modified to be more aligned with research on learning and more aligned with faculty learning goals. Homework has been well demonstrated to improve learning by providing students with additional practice and essential feedback on their learning.

In the departments where we see greater than 80% of the faculty involved in the SEI project, departmental cultures are changing. We recently received an unsolicited letter which provides an outside perspective on how the culture of one department has changed:

-----Original Message-----

From: Valerie Sloan [<mailto:val.sloan@comcast.net>] Sent: January 27, 2009 12:20 PM

To: carl.wieman@ubc.ca

Subject: CU Geology SEI

Dear Dr. Wieman,

I am teaching an introductory course at CU Boulder's Geological Sciences department this semester (a one-off) and upon beginning preparation in December, I heard about the SEI post docs as a resource. Since then I have received a tremendous amount of resources, and a considerable amount of feedback and help from Andrea, Jennifer, Leilani, and Stephanie Chasteen which has triggered what for me has been an Earth-shattering paradigm shift in how I think about teaching science. I wanted to thank you for having created a movement in the direction of interactive teaching, and I wanted to tell you that I am so extremely impressed at what these post docs have done in terms of changing the department. I did my Ph.D. here ten years ago and the shift in attitude towards teaching that I see is phenomenal. The chair and several faculty are fully on board in supporting a move in this direction, and I see signs all over the place of faculty making changes to how they are teaching, such as using clicker questions and asking students to draw conclusions in place of telling them what they should know. I think it is not surprising that the faculty were apparently reluctant to accept new ideas on how to teach, but what is surprising is just how much change the SEI postdocs have managed to create in one department in a short few years. It's a real testament to them. They are enthusiastic, insightful, willing to help, and work hard, and so I suppose it shouldn't be surprising, but nonetheless, I'd say that the Earth has shifted around here for the better. This is apropos of nothing, but I just wanted to pass along my observations as someone returning to a department Before and After the SEI postdocs got here and your ideas have been disseminated. It's fantastic. And thank you!

*All the best,
Valerie Sloan*

Last year, the central SEI administered a formal web-survey of the faculty of involved departments concerning the SEI and how they view it and benefit from it. We received 96 faculty responses from the 5 participating departments. Faculty report that SEI efforts have significantly impacted both the frequency and quality of faculty discussions about education, with 72% reporting an increase in their communication with other faculty members and 61% reporting a change in the nature of these discussions. Overall, 83% of the faculty respond that the SEI efforts are having a positive impact on their departments with 16% either not responding or seeing no net overall impact (only 1 faculty reported a negative impact).

B. Publications and talks

Over the past 3 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 too; 2) it directly engages some faculty in publishing peer-reviewed research in this area and other faculty take notice; 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.

Last spring, Tin Tin Su (MCDB faculty) wanted to know whether student-student discussion during clicker actually helped student learn and made them better able to answer future questions correctly. Partnering with Michelle Smith (STF) and receiving advice from SEI central and others, these two designed and conducted a research study to answer this question. In Fall 2008, this pioneering work was published in *Science* magazine and received widespread national attention for establishing the importance of the pedagogical approach when using clickers.

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

Molecular, Cellular, and Developmental Biology:

“Why Peer Discussion Improves Student Performance on In-Class Concept Questions”, M.K. Smith, W.B. Wood, W.K. Adams, C. Wieman, J.K. Knight, N. Guild, and T.T. Su, *Science*, 2009 Jan 2;323(5910):122-4.

“The Genetics Concept Assessment: A New Concept Inventory for Gauging Student Understanding of Genetics”, M.K. Smith, W.B. Wood, and J.K. Knight, *CBE Life Science Education*, Winter;7(4):422-30.

“A combination of Peer Discussion and Instructor Explanation Provides an Effective Way to Discuss In-Class Concept Clicker Questions”, M.K. Smith, W.B. Wood, J.K. Knight, and K. Krauter, *CBE Life Science Education*, in preparation.

“Different and Not Equal: how non-majors and majors approach and learn genetics”, J.K. Knight, M.K. Smith, *Journal of Life Science Education*, in preparation.

“Small Group Work Enhances Student Learning in a Large Lecture-Based Introduction to Cell and Molecular Biology Course”, J. Shi, A.N. Guild, J. Martin, J.K. Knight, Q. Vincens, and B.W. William, *Journal of Life Sciences Education*, in preparation.

“Assessing Student Learning of Biology Using a New Introductory Biology Concept Inventory”, J. Shi, A.N. Guild, J. Martin, J.K. Knight, and B.W. William, *Journal of Life Sciences Education*, in preparation.

Chemistry:

“Implementation and Impact of Undergraduate Learning Assistants in General Chemistry”, L. Langdon et al., *Journal of College Science Teaching*, in preparation.

“Student Understanding of Acid Concentration and Strength”, L. Langdon et al., *Journal of Chemical Education*, in preparation.

“Evaluation of a Student-Centered Recitation Model”, T. Pentecost et al., *Journal of College Science Teaching*, in preparation.

“TA Training that Integrates Pedagogy and Content”, T. Pentecost et al., *Journal of Chemical Education*, in preparation.

Geology:

“Interactive strategies to encourage student participation and learning in a college-level Environmental Geology course”, L. Arthurs and A. Templeton, *Journal of Geoscience Education*, submitted.

“Expanding the use of CRS: CRS integration with in-class group activities in large classes”, L. Arthurs, *Inaugural Clicker Conference Proceedings*, submitted.

“Development of an Introductory Oceanography Concept Inventory Survey”, L. Arthurs and T. Marchitto, *Journal of Geoscience Education*, in preparation.

“Inspire students to excel through service learning: case study of Hurricane Katrina”, L. Arthurs, *Chronicle of Higher Education*, in preparation.

“Science vs. Pseudoscience”, L. Arthurs and D. Duncan, *Astronomy Education Review*, in preparation.

“Student Behavior Answering In-Class Questions Using Clickers vs. Raising Hands in a Large Introductory Physical Geology Course”, A. Bair, *Journal of College Science Teaching*, in preparation.

“Is Density a ‘Threshold Concept’ in the Geosciences?”, A. Bair, *Journal of Geoscience Education*, in preparation.

“Student Misconceptions and other learning difficulties with Physical Geology Concepts: A Review of the Literature and New Information on Student Thinking in Introductory College Courses”, A. Bair and H. King, *Journal of Geoscience Education*, in preparation.

“Gender-Related Change in Undergraduate Student Interest in Geology Courses”, H. Houlton and J.A. Stempien, *Journal of College Science and Teaching*, in preparation.

“Survey Tool for Assessing Student Attitudes about Learning Geology: The Colorado Learning Attitudes about Science Survey”, J.A. Stempien, *Journal of Geoscience Education*, in preparation.

Integrative Physiology:

“How Not to Lose Your Students in Concept Maps”, K. Semsar, F. Benay, and S. Kennedy, *Advances in Physiology*, in preparation.

“Does It Matter How Study Groups are Formed?”, D. Mood and F. Benay, *Journal TBD*, in preparation.

“Peer Feedback Increases Both Attitudes & Learning in a Physiology Critical Thinking Course”, K. Semsar and J. Casagrand, *Journal TBD*, in preparation.

“Measuring Course Reform through the Cognitive Difficulty of Exams”, J. Casagrand et al., *Journal TBD*, in preparation.

Physics:

“Transforming Upper-Division Electricity and Magnetism”, S.V. Chasteen and S.J. Pollock, *PERC Proceedings 2008, AIP Press; 2008*.

“Students Understanding of Ampere’s Law”, C. Wallace, S.V. Chasteen, and S.J. Pollock, *Physical Review Special Topics*, in preparation.

“Thoughtful Change: A model of research-based course reform”, S.V. Chasteen, S.J. Pollock, C.E. Wieman, K. Perkins, et al., *Journal of College Science Teaching*, in preparation.

In addition, SEI central is preparing the following papers for publication:

“Development and validation of instruments to measure learning of expert-like thinking”,
W.K. Adams and C.E. Wieman, in preparation.

“A model for creating research-based change in college science education: the Science Education Initiative.”, K.K. Perkins and C.E. Wieman, in preparation.

Finally, numerous talks given by SEI Central and Department-based STFs and faculty are drawing national and international attention to the progress being made by the University of Colorado in science education. In 2008, Wieman gave over 20 talks highlighting CU’s SEI. Notably, Wieman was selected for his CU/UBC SEI work to give a keynote address at the Facilitating Change in Undergrad STEM Conference. The STFs attend national meetings in their respective disciplines and have been receiving recognition for their work. For example, Semesar (STF IPHY) has been asked to join a national panel on physiology education reform, Langdon (STF CHEM) is advising on a national chemistry assessment project, and Stempien (STF GEOL) worked with collaborators in geology education to win an NSF grant focusing on student attitudes about geology.

IV. Budget summary

A summary of the budget expenditures for Jan 2008 – Dec 2008 is provided here. Expenditures for each of the departments can be found in Appendix A. The expenditures are approximately \$860,000 per year, and are being budgeted to allow the \$1,000,000/year funding through 2010 to support most of the project to the end of 2011. As in all previous years, the roll over looks large, but is merely a budget timing artifact. The timing when money was released to the SEI significantly proceeded when departments could actually hire STFs and start spending the money. In reality, the current expenditures are consistent with the long term budget plan.

SEI Budget 1/08 – 12/08	
Income	
SEI	\$1,000,000.00
Roll over	\$1,546,270.76
Total Income	\$2,546,270.76
Expense	
Geosciences	\$165,375.00
IPHY	\$141,750.00
MCDB	\$141,750.00
Chemistry	\$141,750.00
Physics	\$77,175.00
SEI Central Expenses	\$191,667.82
Total Expense	\$859,467.82
Remaining Account Balance	\$1,686,802.94
FY06 & FY07 Correction	-4501.29

V. SEI in Chemistry

A. Departmental structure of SEI program

1. People:

Faculty Director: Professor Robert Parson.

Chemistry Education Specialists: Dr. Laurie Langdon, Dr. Thomas Pentecost

Faculty Working Groups: see below.

2. Departmental structures / decisions

Overall departmental oversight is provided by the Chair, Professor David Walba, 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 Walba, Bierbaum, Koch, James T. Hynes, Kevin Peters, Robert Kuchta and Deborah Wuttke, plus Drs. Asirvatham, Hendrickson, and Langdon) advises the Chair in matters involving new courses and course transformation. 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, Bierbaum, Wuttke, and Veronica Vaida, together with Drs. Susan Hendrickson and Matthew Wise (instructors), Drs. Christine Kelley and Lynn Geiger (instructors and academic advisors) and Drs. Langdon and Pentecost.

B. Course-related efforts

1. *CHEM 1111, General Chemistry 1.*

a. 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.)

b. Description of ongoing activities

i. Learning Assessment: instruments and findings

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 two years, the overall negative shift in attitudes has not gone away, but the negative shift in “chemical thinking” has diminished (and in some cases become positive.)

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 2008. Learning gains were about 15% in the spring and 25% in the fall. Detailed examination of the results in various areas targeted by the survey suggest that compared to previous years, students have acquired more facility with translating chemical equations into physical pictures of atomic and molecular behavior, but also reveal some areas, such as thermochemistry, where conceptual learning appears to be minimal, even after the instructor deliberately targeted this area both in lecture and in recitation tutorials. Because of the paucity of calibrated, validated quantitative assessment tools in Chemistry (a search of the literature revealed that essentially all of the surveys that are currently used trace back to two research projects, one of which is still in progress), alternative measures of progress are needed. To this end, Langdon and Pentecost have been carrying out student interviews in both Chem 1111 and its successor course, Chem 1131. These interviews have been used to modify or replace questions in the survey.

ii. Changes in course instruction

Lecture: The Department began using clickers and concept tests in general chemistry lectures in fall 2003. However, classroom observations suggest that they have not always been used in the ways that research on student learning has shown to be most effective. In Spring 2008, the Chem 1111 instructor made a systematic attempt to increase the level of interactive engagement during concept tests, by emphasizing peer discussion and having students defend their answers to the whole class. This instructor reports that the quality of student-initiated questions improved dramatically, and that there appears to be significantly improved performance on conceptual exam questions that relate to the areas specifically targeted. It is not known why these gains are not reflected in the concept survey. (The Spring 2008 Final Exam included two questions that were designed to be isomorphic to questions from the concept survey. The score on the exam question was twice that of the post score on the concept question. Two hypotheses come to mind : either the students took the question more seriously during the exam, or they had had an opportunity to review the material, which came from the early part of the course, before the exam but not before the survey.)

Recitation: In fall 2007 Dr. Pentecost developed a set of Tutorial worksheets to be used by Teaching Assistants in the weekly recitation sections. These were used in both Spring and Fall 2008; in addition, undergraduate Learning Assistants were added to the recitations. The Tutorials aim to synthesize conceptual issues with conventional problem solving, with the goal of presenting students with a more

unified perspective on chemistry as a science. Preliminary results from post-course administrations of the Concept Assessment, as well as student interviews, suggest that these strategies have yielded a meaningful increase in student ability to represent many chemical processes in molecular terms.

c. TA training.

Because of the size of the class, Chem 1111 involves a large number of Teaching assistants. Most of these are first-year graduate students. These students have traditionally received a few days of TA training during their first week at CU, focused on such issues as laboratory safety, classroom management, and microscale teaching activities. In the Fall term of 2007, this training period was extended by three days for a subset of the entering graduate student class. The extended training included a more thorough instruction in pedagogical fundamentals and interactive engagement approaches, as well as to better assess the TAs' understanding of the course content. Subsequent interviews of students and faculty yielded a strongly positive response, so in Fall 2008 the extended training was (after some modification) given to all entering graduate students. The Department paid for this program using a portion of its general chemistry course fees.

2. *CHEM 1131, General Chemistry 2*

a. 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.

b. Description of ongoing activities

i. Learning Assessment:

Attitudes: The CLASS survey has been administered to this course since 2004. As with Chem 1111, the principle result is that students move away from the attitudes of experts after instruction. In Fall 2007, however, this shift, while negative, was statistically indistinguishable from zero (-0.5 %), the first time that this has ever been achieved in a large Chemistry classroom at CU. This success was not replicated in Spring 2008, where negative shifts ~4% were seen, even though nearly all of the components of the courses (including those transformed in the previous year) were the same. It is not known whether this difference is due to student demographics or to instructor effects (the spring instructor, while experienced, had not taught this course before.) The results of the Fall 2008 survey have not yet been examined.

Concepts: The preliminary Concept Assessment Survey administered in 2007 was extensively revised, with the primary goal being to focus on a single major concept area, Chemical Equilibrium and acid-base chemistry. Both published research and informal instructor surveys have shown that this concept area is one of the most difficult in the entire general chemistry course. The SEI Chemistry group,

in consultation with SEI central, decided that acquiring better assessment of student understanding in this area should be a primary focus of SEI work in this course. To this end Dr. Langdon carried out in-depth student interviews throughout the year, and these are continuing during the coming year. In Spring 2008, the normalized learning gain on the concept survey was 0.28 – not significantly different from previous terms.

ii. 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. Only minor changes to instruction were made during 2008. Classroom observations and faculty interviews suggest that clickers are now being used in more effective ways than when they were first introduced.

3. CHEM 1151 and 1171, Honors General Chemistry

This course sequence is taken by students whose background and placement exams indicate an especially high level of preparation in high school chemistry, physics and mathematics. The course material roughly parallels that of CHEM 1111/1131, but with more detail and at a higher level. In Fall 2008, Dr. Pentecost worked with the course instructor to improve instruction in the first third of the course. Chem 1171, Honors General Chemistry II, is generally regarded as successful – it is to date the only Chemistry course to display significant positive shifts in the CLASS assessment.

4. General Chemistry Sequence (1111, 1131, 1151, 1171)

a. Structural changes in the General Chemistry Program

In Fall 2008, the Department voted to break up the traditional Chem 1111/1131 sequence along two lines: first, to separate the Lecture course from the Laboratory, and second, to create a new course for chemistry majors (this is distinct from the Honors General Chemistry course described above.) The Majors course, estimated enrollment about 170 students in one section will begin in Fall 2009; it will initially be taught by Distinguished Professor Thomas Cech. For logistical reasons the Laboratory course will not be formally created for two years, but beginning in Spring 2009 an additional Faculty member has been assigned to the present General Chemistry course, and this faculty member has been charged with managing and improving the laboratory. Professor Parson has taken on this responsibility for Spring 2009 (Chem 1131 only) and Fall 2009 (both Chem 1111 and the new majors course.)

b. Overall considerations regarding general chemistry and the SEI

The strategies adopted for transforming general chemistry teaching– primarily, increased use of peer instruction via clicker concept tests and transformation of recitation into a tutorial format – appear to have resulted in a small improvement in student attitudes, but not in a major increase in conceptual understanding as measured by the concept surveys. It is not clear whether the transformed components are not being effectively implemented, whether structural features of the general chemistry

program (such the fact that recitation takes place in the general chemistry teaching laboratories, as the first part of a 4-hour recitation/lab period) are diminishing their effect, or if the course content and structure needs a more radical overhaul. A review of attempts to transform chemistry education at other institutions shows that radical overhaul can be successful, but that it runs a significant risk of not being sustained. However, the upcoming reorganization of the general chemistry courses, including the creation of an entirely new course, may provide an opportunity for carrying out larger changes than would normally be possible, provided that a broad faculty consensus on the nature of the changes can be attained.

5. *Upper Division: CHEM 4511 and 4411, Physical Chemistry*

a. Background

Fall 2008 saw the first involvement of SEI in upper division courses. Two courses, Chem 4511 (Physical Chemistry I) and Chem 4411 (Physical Chemistry with Biological Applications) were targeted. 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 (the courses have identical prerequisites and satisfy requirements for either major.) In Fall 2008 Chem 4411 was taught by Professor Amy Palmer while Chem 4511 was taught by Professor Robert Parson.

b. Description of ongoing activities

i. Learning goals

Professor Palmer had already prepared a set of learning goals for Chem 4411. Professor Parson began to draft goals for Chem 4511, adapting some from Chem 4411 and developing additional goals for concept areas (such as Chemical Kinetics) not dealt with in Chem 4411. The 4511 goals are highly preliminary and have not yet been evaluated by a broad spectrum of physical chemistry faculty.

ii. Assessment

A preliminary concept survey for Chem 4511 had been developed by Dr. Linda Koch about 4 years ago. In summer 2008, Parson, Palmer and Pentecost revised this survey to more closely reflect the course content now being taught. The survey was focused on concept areas common to both courses (Gases, First Law of Thermodynamics, Second Law, Solutions, Phase and chemical equilibria) and administered at the beginning and end of each class. Dr. Pentecost carried out student interview in both courses throughout the term. While the results from the surveys have not been fully evaluated, some clear trends have emerged. Both classes saw large gains (~ 50%) in the areas of solutions and equilibria, but 4411 saw much larger gains than 4511 (40% vs. 20%) in the areas of Gases and First Law.

iii. Changes in course instruction

Parson, Palmer, and Pentecost explored the use of two distinctly different interactive engagement strategies, both of which are well founded in research on student learning. In Chem 4511, Parson combined in-class clicker concept tests with pre-class “warmup” exercises, in which students are posed conceptual, open-ended questions online before each class meeting. In Chem 4411, Palmer used breakout sessions, in which students solved conceptual problems in small groups, as a part of each class period. Both classes assigned written conceptual homework in addition to traditional numerical problems. Results of student interviews suggest that the written homework helps the students to pull the concepts together. The results of the concept survey suggest either that the breakout sessions are a more effective general strategy than clicker questions in a course at this level, or that the current clicker questions (developed mostly by Parson during the course of the term) do not effectively address student misconceptions in some concept areas.

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. Chemistry SEI has been most active in working with faculty associated with the General Chemistry program and with the Physical Analytical/Environmental divisions of the department.

D. Additional activities of SEI Personnel

Drs. Langdon and Pentecost continue to present results at major conferences in the field of Chemistry Education, including the 20th Biennial Conference on Chemical Education (Purdue, July 2008) and the 236th American Chemical Society National Meeting (New Orleans, April 2008.)

Dr. Pentecost was offered and accepted a tenure-track faculty position at Grand Valley University beginning in Fall 2009.

E. Goals for 2009

1. Begin an intensive study of the Laboratory component of General Chemistry. In Spring 2009, this will be overseen by Professor Parson with the help of two undergraduate Noyce Fellows and some assistance from a part-time graduate student (not supported by SEI). The Noyce Fellows will examine selected laboratory experiments from Chem 1111 (in particular, the experiments associated with Thermochemistry, the concept area from the course for which instruction has been shown to be least effective). The graduate student will examine two experiments from Chem 1131, associated with oxidation-reduction reactions and electrochemistry. There is an extensive body of published research concerning student misconceptions in this area, which can provide a foundation for developing an assessment tool that would measure the extent to which the laboratory experiments do, or do not, address these misconceptions. A preliminary set of learning

goals for the individual Chem 1131 Labs has been drafted by Dr. Kelly; the General Chemistry Laboratory Working Group plans to discuss these, to examine their relationship to the established overall Course Learning Goals, and to draft intermediate level learning goals for the laboratory component.

2. Advise and participate in the creation of a new General Chemistry course for chemistry majors.
3. Continue SEI involvement in upper division courses.
 - a. Chem 4511, Physical Chemistry I:
In Spring 2009 this course is being taught by Professor Vaida, who is using Parson's clicker questions and some homework assignments. Meanwhile Parson is revising and extending the clicker questions written in 2008 to more effectively target misconceptions in thermodynamics. A second round of Chem 4511 interviews is planned. Parson will revise the draft learning goals for this course and present them to other physical chemistry faculty for discussion and further revision. Further student interviews are planned.
 - b. Chem 4411, Physical Chemistry I with Biological Applications
Professor Palmer will again teach this course when it is next taught (Fall 2009) As this course already appears to be highly successful, a major goal of Chemistry SEI is try to sustain her changes (learning goals, in-class breakout activities, conceptual and context-rich homework assignments) when the course is handed off to another instructor.
 - c. Chem 4531, Physical Chemistry II
In 2009, SEI will begin to work with this course, the successor to Chem 4511. Professor Carl Lineberger is teaching the course in Spring 2009 and Professor Mathias Weber in Spring 2010; both have expressed interest in working with the SEI. (Lineberger is using clickers in Spring 2009.) As there is significant overlap between the content of this course (elementary quantum mechanics with chemical applications) and the content of the Modern Physics courses in the Physics department, it may be possible to adapt materials and strategies developed for the latter courses, so the workload on SEI personnel need not be large.
4. Continue to revise, using the results of student interviews, the materials used in General chemistry recitation. The experience of more established tutorial projects (such as the University of Washington Physics Tutorials) strongly suggests that several years will be required to optimize them.
5. Continue work on constructing, revising, and validating concept surveys by conducting and analyzing student interviews, with emphasis on Equilibrium in General Chemistry and Thermodynamics in Physical Chemistry.
6. Continue to refine the highly successful enhanced TA training program.
7. Collect, evaluate, and archive course materials for Chem 1111/1131 and begin archiving for Chem 4511 and Chem 4411.
8. Analyze accumulated data and prepare manuscripts for publication.

VI. SEI in Geosciences

A. Background

Participation in the Science Education Initiative (SEI) in the Department of Geological Sciences (GEOL) is entering its 4th year; since the inception in Jan 2006 of the SEI-GEOL project, we can confidently say that the program has matured to an integral part of the teaching mission of the department and is now a natural part of the faculty's resource and advisement base for pedagogy in geology.

Since it was established, Prof. David 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.

In late August 2008, Prof. Stephen Mojzsis stepped in as Acting Director of SEI-GEOL with Prof. Budd's departure on sabbatical leave for the 2008-2009 academic year. This document therefore reports on the outcomes for 2008 that for the most part are due to Prof. Budd's successful leadership prior to Mojzsis' appointment.

B. Human Resources

In 2008, we were very fortunate to have three postdoctoral STFs present in the department to implement SEI-GEOL strategies across a wider range of undergraduate courses beyond the 1000-level curriculum into 3000-level classes. This became a top priority since the department began, as one of the principle outcomes of its Program Review Panel (PRP) report from 2004 (please visit:http://www.colorado.edu/facultyaffairs/PRP%20Final%20Reports/geology/geology_cycle4.pdf if you would like to obtain a copy of this document) to restructure its undergraduate course offerings and to re-invent existing curriculum to better serve our majors and non-majors.

At the present time, our STFs are Dr. Andrea Bair (lead STF in GEOL), Dr. Jennifer Stempien and Dr. Leilani Arthurs. Dr. Stempien's contract with the SEI ends at the end of Spring semester 2009. A search committee for her replacement is in place, and it will conduct a national search and selection on or before May, 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: For the first two years of the program, focus was on 1000-level courses. As you will see in the detailed outcomes described below, we have now directed our focus on implementation of SEI strategies to key upper division major and non-major core courses. It is noteworthy that the 1000-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. Since we began our participation in the SEI, Geological Sciences has completely revamped its introductory courses (1010, 1020, 1060) in Physical and Historical Geology, and Climate Change, respectively. A crucial new development in our mission has been the implementation of the SEI in our major-track 3000-level courses.

Our work in 2008 saw the further embedment of three STFs in the planning and implementation of SEI strategies with the teaching faculty. We view this as a natural evolution of the role of the SEI STFs in our teaching mission in Geological Sciences as the faculty become aware of the successes of the program and comfortable with the support provided by the Teaching Fellows. It is not hyperbole to point out that the results of our faculty-STF collaborative in the SEI will have positive repercussions for many years to come. It has taken in many cases our faculty out of their comfort zone and exposed them to fresh new ideas about bringing the excitement of geology to our undergraduate students.

Dr. Bair was tasked to continue work with all faculty involved in our large introductory course, GEOL 1010. She also oversaw the transformation of our large upper division majors course, Introduction to Mineralogy (GEOL 3010). This was an important developmental step in our efforts to restructure our undergraduate curriculum because this particular course serves as a gateway for all Geology majors to higher level courses and provides an important real world experience in solid state physics to students in Engineering (structural, chemical, and electrical). She also advised on the development of a new Critical Thinking course in geology (GEOL 4500), and worked with Dr. Stempien to transform the upper division Sedimentology and Stratigraphy course (GEOL 3430).

Dr. Stempien worked with the faculty involved in the two other introductory courses, GEOL 1020 and led development of our new Attitudinal Survey. In an important development, Dr. Stempien spent considerable time and effort to transform and modernize the upper division undergraduate laboratory in Structural Geology (GEOL 3120) with two of the faculty and their teaching assistants. This monumental task involved gathering input from alumni of the department in industry and academia to focus on strengthening to most important skill sets needed and creation of 13 weeks of new laboratory material that places more emphasis on problem-solving.

Dr. Arthurs' has continued her role as SEI-STF to faculty teaching courses related to broadly environmental geosciences (GEOL 2100, Environmental Geology; GEOL 3070 Introduction to Oceanography; and ENVS 1000, Introduction to Environmental Studies). With the Environmental Geosciences group faculty members, she facilitated meetings through which the faculty members of this group were able to successfully revise the existing curriculum for the Environmental Geosciences track, which they believed needed improvement but had not been able to successfully convene in mass to deeply discuss the curriculum and formulate improvements. In the process, a new course offering emerged, GEOL 2001. In addition to revising the curriculum for the Environmental Geosciences track, we also developed the curriculum for GEOL 2100. By the end of 2008, the proposal for the revised curriculum (to include GEOL 2001 and another new course) was approved by the GEOL faculty at large and the official paperwork for GEOL 2001 was submitted for approval to the College of Arts and Sciences.

D. Course Curriculum Outcomes

1. 1000-level courses

a. Physical Geology (GEOL 1010); STF Dr. Andrea Bair

- Eight of nine instructors teaching Introductory Physical Geology in 2008 participated in the initiative by implementing various aspects and/or by actively

seeking input from STF Andrea Bair. This includes implementation and continued modification of learning goals, in-class activities, and homework developed with STF Dr. A. Bair, and associated with the faculty goals identified in the 2007 GEOL 1010 workshop. Dr. Bair provided support and guidance to faculty as they adopted SEI-developed materials for the first time. A notable change in teaching is that all participating instructors are now using iClicker technology and give homework assignments (both were highly recommended by STF).

- Individual faculty learning goals were compiled and used to identify and approximately 80% overlap between different faculty, which went a long way towards our goal of at least 75% consensus goals. Faculty regularly consulted with Dr. Bair on means to improve course materials and teaching methods as well as new information on student learning difficulties.

- Completed in-depth analysis of 1010 student surveys (including surveys on student conceptual understanding of key concepts and on their learning experience); identified practices/materials that are associated with greater student satisfaction and learning, and prepared reports for individual faculty. Improved concept inventory (including validation of many questions through student and faculty interviews). Overall, we observed an approximate 25-30% relative gain in student understanding as measured by the concept inventory questions (depending on the version administered) with sections employing “reformed” methods and materials generally showing higher gain scores (~40-45%). We also report improved student satisfaction with their learning experience over data collected the first year.

- Developed new conceptual questions targeting plate tectonics as key theme, conducted student and faculty interviews, and developed new instructional materials and modified existing material for further testing. Completed analysis of each concept inventory question for each time it has been administered (across 4 semesters and 9 individual instructors), which has allowed identification of common troublesome areas and concepts for which some faculty approaches and materials are associated with greater student learning as measured by the concept inventory gain scores. Produced individual reports for faculty on their teaching and student learning.

- A major priority of faculty teaching 1010 has been the ability of faculty to efficiently archive and share course materials with one another. STF Andrea Bair has been actively involved with the development and improvement of the SEI Materials Archive. Approximately 80% of course materials used for 1010 are now uploaded to the archive system and indexed by topic and category (lecture notes, clicker questions, etc.); some are indexed by consensus learning goals (a major priority for Spring 2009 is for all 1010 materials to be available and indexed by learning goals). Faculty teaching 1010 for the first time since the beginning of the initiative have actively been using the archive system to examine teaching materials in use.

b. Historical Geology (GEOL 1020); STF Dr. Jennifer Stempien

- The three 1020 instructors restructured the content of the lecture material so as to (i) focus case studies as examples of key ideas instead of trying to cover all of geologic time; (ii) move backward through Earth history (rather than forward from

the formation of Earth, as is usual) as decided from the June 2007 GEOL 1020 workshop; and (iii) modify individual lecture level learning goals to fit the new format.

- Out of 107 unique learning goals identified from the instructors surveyed, and overlap was found in all intermediate themes and topics. It was further documented that 45% of individually derived lecture-level learning goals overlap among multiple faculty that have participated with the SEI between Fall 2007-Fall 2008. This analysis was used to create a common learning goals document that all GEOL 1020 faculty can use as a baseline.

- The first test of the June 2007 GEOL 1020 workshop was to have those faculty teaching in the Spring semester focus on preparation of new (and frequent) homeworks that align with new learning goals and shared key concepts. Although this was not planned, one faculty member offered frequent homeworks but with fewer questions per homework, and another offered homework at a similar level of difficulty and with the same goals in mind, but less frequently and with more questions per homework. Our analysis showed that students placed high value on frequent homework since it gave them more feedback from instructor, and often closely tied with material recently covered in class discussion.

- Version 1.0 of a concept assessment was developed for use in the CU GEOL 1020 courses based on the shared intermediate learning goals from the faculty (noted above); it consists of 20 questions on five topics. Some questions were taken from the established Geoscience Concept Survey. Others were composed by STF and participating faculty, and were tested in student interviews over both spring and fall semesters. The outcomes of the CU GEOL 1020 concept assessment based on 82 individual responses that completed both pre- and post-tests were the following: Learning gains were observed in 70% of students and positive gains in 75% of the assessment questions. Questions that did not see positive learning gains were spread throughout the assessment and not concentrated in one topic and we are presently analyzing these data in order to further refine our curriculum strategies.

c. Environmental Geology (GEOL 2100); STF Dr. Leilani Arthurs

- Based on the results of the GEOL 2100 Faculty Feedback Report for the first iteration of GEOL 2100, recommendations were made for different aspects of the course, classroom environment and interactions, concept challenges for students, and advice for changes to overarching themes to be used in the second iteration of GEOL 2100.

- Analysis of the pre- and post- CLASS surveys (as in GEOL 1020, above) provided the data needed to modify the goals of the course and two undergraduate peer instructors were employed to assist in the design and implementation of new in-class activities for this second iteration of the GEOL 2100 in 2009.

d. Introduction to Environmental Studies (ENVS 1000); STF Dr. Leilani Arthurs

- As part of our broader role in the development of curriculum for the Department of Geological Sciences, we also worked with our partners in the Department of Environmental Sciences with pre- and post-CLASS survey results.

2. 3000-level courses

a. Introduction to Mineralogy (GEOL 3010); STF Dr. Andrea Bair

- STF Dr. Andrea Bair and faculty member Prof. Joseph Smyth partnered to begin a much-needed transformation of the Mineralogy course. The major focus was on improving the lecture time to be more interactive, identifying common student learning difficulties, improving the conceptual focus of the course, more closely linking lecture and laboratory, and improving laboratory activities. We established a working draft of course, topic, and lecture-level objectives and goals.

- Lecture materials and assessments were modified, and clicker questions were developed in alignment with the learning goals constructed by the STF and faculty. 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. With the TAs, a new laboratory activity focused on the application of skills and concepts students was developed, and the new exercise was well-received by students. The STF attended and observed or participated in nearly all laboratory and lecture sessions, and promoted student interactivity. At the present time, we are in the process of examining student responses to an end-of-semester survey on student views of their learning experience.

b. Structural Geology (GEOL 3120); STF Dr. Jennifer Stempien

- A working group was established in order to begin to tackle the first of the upper division laboratory assignment to be transformed. This included two faculty members associated with the course (Prof. K. Mueller and Dr. K. Mahan), two graduate students, and the STF. The working group met weekly.

- Learning goals associated with the structure laboratory assignments *i.t.* went from 68 individual tasks – where only 18% were shared between multiple instructors as compiled from 4 years of previous labs – to a list of 31 agreed-upon learning goals and skills for both instructors. In addition to this achievement, the goals were changed from being dominated by repetitive computational tasks to more application and interpretation within a given scenario or problem.

- The learning goals developed for the Structural Geology laboratory exercises were deliberately shared with members of the Department of Geological Sciences' Alumni Advisory Board. The purpose of this was to ask for their input on what industry employers look for in a potential geology employee. Alumni input unambiguously showed that map interpretation, and experience with working with faults, were used as the basis for our decision to modify laboratory exercises for the last half of the Fall 2008 semester.

- Format of the labs changed noticeably over the course of semester: From separately weekly assignments that consisted of primarily practicing a technique over and over again, to multi-week assignments that presented a problem to the students that required thought, skill and creativity. The format of the multi-week assignments built upon knowledge accumulated in the previous week and what they needed to know in order to complete the goal for the following week. Students were challenged to propose a plan on how to achieve goals.

- In sum, 13 weeks of laboratory materials were compiled and shared with all members of the working group. This “kit” includes handouts, maps, images, questions, answer keys and STF comments.

- The working group identified the following as critical components of any structural geology student’s “toolkit” that needs to be addressed and overcome in future transformations of the structure laboratory: Identify and recognize the timing of unconformities and other major geologic events using maps; visualize a 3D geologic feature from 2D representations; contrast linear from planar features in a rock and describe the relationship between the two; apply geometry to a dipping bed; and basic drafting skills.

- It was noticed over the course of the semester that students frequently left the laboratory session early and arranged to meet and work in groups later in the week outside of the scheduled class time. This behavior exhibited itself despite (i) frequent comments from students to the STF (both in surveys and in-person) that they value working with their peers and talking with TAs; (ii) students often visited TAs and the STF in office hours with questions regarding lab material; and (iii) the instructing team explicitly stated that students who stay for the entire scheduled laboratory periods complete the assignments faster and score higher than those that do not. Some potential causes were identified, and the structural working group plan edited the assignments to stress the value of remaining in the scheduled laboratory session.

- Two sets of surveys were administered to the students regarding the labs section of the structural geology course: (i) the Colorado Learning Attitudes about Science Survey, and (ii) the Student Attitudes about Learning Gains. The data are currently being processed, but major themes in student responses thus far are:

- Students enter the upper level courses still unsure about what types of problems geologists solve and their own ability to solve those problems. This is similar to survey responses from students entering another upper-level geology course from data collected in Spring 2008.
- Students were split on their preference for laboratory assignments completed in a week, and those that were completed over multiple weeks. This split appears to have a correlation with a student opinion on whether or not memorization is the key to succeed in the upper level course, but more analysis is necessary.
- Initial frustration on laboratory assignments that were presented with little step-by-step instruction, but students felt more confident once they solved the assignments.
- The grading scheme used in the laboratory assignments failed to provide clear feedback on what students needed to work on to learn the material.
- Group work was essential to succeed in the course, and most students preferred to work with their peers over the usual laboratory lecture from an instructor.

c. Introduction to Oceanography (GEOL 3070); STF Dr. Leilani Arthurs

- Baseline data were collected in Spring 2008 for the presentation of this course without the iClicker technology for future comparisons with results of the second iteration of the collaboration (Spring 2009, with clickers).
- First the first time in this course, learning goals were developed and a concept inventory survey was created to measure student learning gains.
- The faculty were presented with a GEOL 3070 Faculty Feedback Report, addressing the first iteration of SEI-GEOL 3070 collaboration. The report included student misconceptions and learning difficulties, recommendations for implementation of clickers, and 23 sample clicker questions based on classroom observations and learning.

E. Departmental Deliverables

a. iClicker support and training; STFs Bair, Arthurs, Stempien

- All three STFs in Geology have been active in supporting faculty using iClicker software and hardware; particularly, we have offered beginning of semester training sessions for faculty using the iClicker system for the first time and provided technical support throughout the semester when requested by faculty. Nearly all faculty teaching introductory courses now use iClickers and clicker questions.

b. Faculty Brown Bag Series; STF Dr. Leilani Arthurs

- In Fall 2008, SEI-GEOL started a faculty brown-bag series which met 5 times over the course of the term. Topics were selected by faculty through a survey process in which 10 faculty participated. Brown bags addressed the 5 topics: 1) Student misconceptions in geology, 2) Content interactions and student thinking, 3) Maintaining student interest & enhancing learning, 4) Classroom demos, and 5) SEI-GEOL's future. This brown bag series is being continued in Spring 2009 and are focusing on GEOL faculty presenting to each other about the work they have been doing in their courses to improve student learning.

c. Tutoring and Study Room; STF Dr. Leilani Arthurs

- In Spring 2008, it was evident that there was a need and a demand for GEOL tutors (as stated by students and faculty). After contacting and communicating with many campus and student organizations, we learned that GEOL tutors did not exist on campus that provided free tutoring services. In response to this demand STF Dr. Arthurs talked with faculty and staff in PHYS, CHEM, and MCDB to learn how they have met the tutoring needs of their students. STFs Bair and Arthurs worked together to develop a proposal for instituting a tutoring program within Geological Sciences. The proposal was accepted and the department provided funding both for the tutors and a room, which is now called the "Tutoring & Study Room."
- Fall 2008, we opened the Tutoring & Study Room (T&SR) with 10 tutors who, collectively, were able to assist in 21 different GEOL courses. Over the course of the semester, data were collected of the number of students used the T&SR, what courses they were seeking assistance in, and the reason for their visit (e.g. homework or test preparation). STF Arthurs prepared a mid-semester report with this

information and it was distributed to the tutors and select faculty members (e.g. Chair and GEOL-SEI directors).

- From the start of this tutoring experiment, concern was raised over the sustainability of the T&SR; this has now been resolved. The department has invested a 0.25 Teaching Assistantship to this program in the role of Head Tutor and a permanent room has been established.

d. Development of interactive simulations (PhET); STF Dr. Andrea Bair

- STF Andrea Bair has worked in consultation with the PhET simulation project to support development of simulations on glacial processes, density, and radioactive decay.

e. Capturing Student Attitudes regarding the Geological Sciences; STF Dr. Jennifer Stempien

- Analysis of response data to the Colorado Learning Attitudes about Science survey from multiple Geol 1010 sections reveal six categories among 35 statements. Four of the categories (Personal interest, Real World, Problem Solving general, and Problem solving confidence) have strong overlap with similar categories in both the Physics and Chemistry CLASS versions. The remaining two categories have different grouping of statements than other CLASS versions.

- Interviews conducted within first week of semester of GEOL 1010 students imply that students express little understanding of the types of problems that geologists solve and what geologists do compared to their impression of other scientists.

- Preliminary analysis of CLASS data from students that have participated in GEOL 1010 followed by GEOL 1020 suggest that positive shift is student beliefs about learning geology occurs after completing an introductory physical geology course, yet there is a negative shift in student beliefs after completing a consecutive semester of historical geology. These shifts appear to be concentrated in their beliefs about problem solving which is a cause for concern by us. We are now actively involved in improving our problem solving focus for GEOL 1020.

f. Teaching Assistant Summer Training Workshop; STF Dr. Leilani Arthurs

- In Summer 2008 a 1.5 day TA training workshop was held that introduced the best pedagogical practices. Evaluations of this workshop showed that the TAs all found it very useful.

- As a follow up to the summer training, Prof. Budd and Dr. Arthurs discussed the possibility having weekly TA meetings in which the STF would provide ongoing pedagogical training. It was suggested that 3 additional meetings be held (early in the semester, mid-semester, and before the end of the semester).

F. Goals for 2009

1. GEOL 1010 Geology 1 (Physical Geology): Major goals for this course center around revisiting individual faculty goals and practices to arrive at consensus goals shared by most faculty, identifying improved student learning associated with materials,

approaches, and practices, and final development and validation of a conceptual assessment instrument to assess student learning of key faculty goals.

- Revise consensus learning goals. STF writing goals based on faculty exams, homeworks, and other assessments (such as clicker questions). These will then be compared with faculty-stated goals from our compiled list, and an updated and revised list of consensus goals (those which a majority of faculty share) will be made available to faculty for review.
 - Index teaching and assessment materials (now uploaded to the SEI archive site) to consensus and individual faculty goals.
 - Revise and validate concept inventory based on revised consensus learning goals, and focused on a few major conceptual areas (i.e., plate tectonics, rock-forming processes, and surficial processes). Many questions that have now been used in multiple sections of the course are now validated, but additional questions are needed that more closely match faculty learning goals.
 - Continue development of teaching modules that address student learning difficulties; for example, we're working on a module that addresses how we know that the Earth's mantle is composed of solid rock rather than molten (a very common student misconception is that there is a layer of magma in the mantle that is connected to volcanoes on the surface).
2. GEOL 1020 Introduction to Earth History: Spring 2009 is the last semester for intense SEI involvement assisting faculty with transforming their individual courses to the new format proposed in the Historical Geology summer 2007 workshop.
 - Focus on developing clicker questions and best practices in the classroom based on previous SEI work (both faculty are using clickers this term).
 - Products and results from SEI involvement in GEOL 1020 will include (a) clicker question and assessment on SEI course archival system, (b) documentation of the new format and some example case example (e.g. climate transition in late Cretaceous), and (c) a second faculty summer workshop in May 2009 to discuss their experiences with the new format and developed material.
 3. GEOL 1030: Introduction to Geology Lab (partial SEI collaboration). Facilitate implementation of undergraduate Learning Assistants into 5 sections with 5 different primary instructors. This includes facilitating weekly meetings with the LAs, coordinating 2 large group meetings (all TAs and LAs for GEOL 1030) with Lon (faculty oversight of GEOL 1030) during the Spring 2009, and observing several different lab sections with and without LAs.
 4. GEOL 2100: Environmental Geology (full SEI collaboration)
 - This course was developed from the ground up and incorporated the latest in research-based educational strategies and techniques, from defining learning goals to implementing large-scale in-class group activities. Fall 2008 marked the second and last iteration of SEI collaborations with this course.

- Complete the data analysis of the Fall 2008 CLASS (for environmental sciences) including results of the open-ended Additional Questions section and a comparison of the pre- and post-instruction CLASS survey questions.
 - Prepare next version of the concept inventory survey, using redefined learning goals.
 - Upload lecture PowerPoint slides, HW, in-class activities, and other course materials to the SEI Archive System.
5. GEOL 3010 Mineralogy: We anticipate SEI support for this class again in Fall 2009; our goals in the meantime involve summarizing what we learned from last semester as far as student learning difficulties, our plans to address those difficulties, and developing a concept inventory to assess student learning.
- Summarize data on student attitudes and learning from multiple class observations, assessments, and surveys.
 - Some interviews with students now in the Petrology course, which is generally considered next in the major track, focusing on continuity and discontinuity between the courses.
 - Compile laboratory exercises (including modifications to existing labs and a new exercise) into a lab book (at least digitally).
 - Draft questions for a concept inventory based on observed student learning difficulties.
 - STF will complete report to faculty addressing summarized data, observed learning difficulties, and recommendations for the next phase of reforms.
6. GEOL 3070: Introduction to Oceanography (full SEI collaboration)
- Guide instructor in implementation of clickers and clicker questions into lecture.
 - Assess effect of clicker implementation on student participation and learning.
 - The primary aspect of course transformation this course is involved with is the implementation of clickers.
 - Regularly conduct and record classroom observations.
 - Administer pre- and post-instruction survey to assess student attitudes towards learning oceanography (CLASS for oceanography).
 - Administer pre- and post instruction survey to assess student learning gains (Introductory Oceanography Concept Inventory Survey or IO-CIS, developed and validated during Calendar Year 2008)
 - Spring 2009 will be the second and last iteration of SEI collaborations with this course.
 - At least two manuscripts based on this collaboration will be prepared during Calendar Year 2009.
 - Learning goals at the concept level were defined during Calendar Year 2008.
7. GEOL 3120 Structural Geology:
- Develop second revision for new Structural Geology Lab manual and teaching guide for the faculty and teaching assistants for use in the Fall 2009 semester. These revisions

will use the data collected and input from the Structural Teaching Team, 2 faculty and 2 teaching assistants. They will include: (a) redesigning the first four labs to emphasis basic mapping skills and geological representation, (b) improving clarity and presentation of tasks and goals to the students (c) presenting student difficulties and misconceptions identified from lab, and (d) summarizing best practices for the TA on the innovation design used for the labs which appears to be inefficient to novice instructors. Both digital and paper copies of the redesigned lab material will be made available to the faculty.

8. GEOL 3520: Environmental Issues in the Geosciences (partial SEI collaboration)
 - Meet weekly with the instructor to review course materials for coming lectures and provide recommendations for engaging students in active learning.
 - The instructor has learning goals associated with each lecture.
9. GEOL 4500-001 Critical Thinking: Rates and Dates in Earth Science: We are currently in the process of developing this course from scratch. Our major goals are to:
 - Develop a set of course and topic-level learning goals related to both conceptual understanding of geologic time and other geologic concepts, and critical thinking and communication skills, along with assessments that coordinate with those goals.
 - Develop and test grading rubrics for assessing student writing assignments.
 - Develop concept survey-type questions relating to student understanding of geologic time concepts (some were already given as a pre-test).

Additionally, geologic time concepts are notably difficult for students and are included in learning goals in introductory as well as upper level geology courses; we expect that our experience in testing out teaching and learning materials and approaches in this small enrollment course will allow improved teaching and learning of these concepts across the curriculum.

10. Tutoring & Study Room (T&S Room). Direct the Tutoring & Study Room, provide direct supervision of the Head Tutor, oversee Tutors and daily operations, assess effectiveness of Head Tutor role in sustaining the Department's T&S Room, and provide mid-semester and end-of-semester reports of student utilization of the T&S Room. (The T&S Room is the only place on campus where any student can receive free GEOL tutoring.)
11. Course material has begun to be added to the SEI course resource data base starting in December 2007 using Geol 1010. Material from the following courses are beginning to be uploaded to the site and shared among faculty; Intro to Geology I (GEOL 1010), Intro to Geology II (GEOL 1020), Environmental Geology (GEOL 2100), and Mineralogy (GEOL 3010)
12. Continued professional development of the STFs is evidenced by their presentation of total 6 papers at the annual Geological Society of America and American Geophysical Union meetings in 2008, their being asked to review manuscripts and proposals, and invitations to speak at departmental seminars, professional meetings, and teacher training workshops.
13. A collaborative proposal to the NSF was awarded to Jennifer Stempien as PI and David Budd as Co-PI. The proposal involves collaboration with 10 other schools (community

colleagues, private 4-year colleges, comprehensive universities) to: 1) use a common instrument to investigate how aspects of the affective domain, in particular student motivation, vary for students in introductory Geoscience courses at a range of institutions; and 2) identify if and how those aspects vary with instructor, learning environments, and class characteristics. Dr. Stempien serves as a primary data analyst for the two- year study and a workshop for all participants involved will be held at CU-Boulder in Summer 2009 to discuss the results and to identify best-practices instructor can use in the introductory classroom.

VII. 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 (part-time; beginning Aug. 2008), 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.
 - i. New physiology course begins. IPHY 3480-Humany Physiology II has now been taught for two semesters and is in the process of identifying learning goals.

B. Course-related efforts

1. IPHY 3470: Human Physiology I

A total of 173 students were served in 2008. Two faculty members were involved in this course. During the spring semester, there were two TAs involved with the course, while only one TA was involved during the fall semester.

Ongoing activities:

a. Improving learning goals and course changes

- i. The learning goals were finalized during the Spring and Summer 2008 semesters.
- ii. The faculty has now taken on the development of clicker questions. Our role in PHYS I is now of assistance, feedback, and to archive the activities for dissemination to the IPHY 3470 faculty members.

- iii. Homework assignments have been maintained from last year, with faculty now making their own edits and additions to the homework.
- iv. In order to continue to engage students in discussion, faculty members continue to use the iClicker in lecture. Various uses of clickers include regular reading quizzes, comprehension, and prediction from current and previous lectures.

b. Refining an assessment tool

- i. The assessment tool has been modified since 2007. Each semester, modifications and testing in the classroom has occurred. Analysis of the assessment results has been shared with the faculty for further input.

c. Understanding student learning and thinking

- i. Evaluation of students' homework, student questions, and discussion from in-class clicker questions in the Spring 2008 semester were used to evaluate student learning and misconceptions. These data were used to improve the homework assignments.

d. 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.

2. *IPHY 3410: Human Anatomy*

In the 2008 academic year, there were a total of 674 students served. Three faculty members were involved with this course. No TAs were involved with this course during either semester.

In Spring 2008, STFs continued to attend classes and document student questions. This led to further development of online homework activities and research studies.

Ongoing activities:

a. Improving learning goals and changes in instruction

- i. Learning goals have been developed with input from all three anatomy faculty members. The STFs provided input on the development of materials to aid student learning of these goals. Feedback from new anatomy faculty will allow for revisions and discussions of the effectiveness of the goals
- ii. Faculty members continue to develop their own clicker questions, with the STFs providing occasional feedback and archiving.
- iii. The STFs have been providing feedback on exam questions including clarity and alignment with learning goals.

- iv. Faculty have adopted the online homework assignments and continue to expand and modify with the assistance of STFs.

b. Developing an assessment tool

- i. An assessment tool that was developed by the anatomy instructors, with feedback from SEI, has undergone intense revisions. The revised assessment tool now includes 33 questions. Interviews and validation of the assessment tool has taken place, and is currently administered the first and last week of the course.
- ii. After participating in the assessment, students were asked to explain their answer choices on the pretest and posttest. These data have been used to validate the current question set, to develop improved distracters, and to document common student misconceptions of students entering the course.

c. Understanding student thinking and learning

- i. Spring 2008: In order to help understand student thinking, the STFs have been documenting student questions and responses to oral questions during class time. They have also been analyzing student responses to clicker questions and responses to open-ended questions on the pre/post-assessment tests.
- ii. Student interviews: Following each of the three mid-semester exams, we interviewed 7-10 students each exam on appropriate assessment questions for the pre/post survey that aligned with both the major learning goals from that section of the course and common wrong answers on exam questions (all exams are multiple choice). Interviews also include questions about student's approaches to studying the material. As of the end of the fall 2008 semester, the STFs have interviewed a total of 32 students.

d. Developing resources for faculty

- i. Weekly meetings have been held with the current anatomy faculty to provide feedback on the ongoing development of homework and exams. The major ideas discussed during each meeting were documented, including several common student misunderstandings of that particular week's topic.
- ii. 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.
- iii. 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 helproom) 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.

3. *IPHY 3480: Human Physiology II*

In the 2008 academic year, there were a total of 174 students served. Two faculty members were involved with this course. One TA was involved with this course each this semester.

a. Learning goal development

- i. The STFs have worked with the faculty members to help develop a draft of learning goals for the PHYS II course. These goals are aligned with pages and figures in the text.

b. Developing an assessment tool

- i. An initial assessment tool was developed using questions published in the *Advances of Physiology Journal* and with faculty. It was administered in the spring of 2008.

c. 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. They have also been analyzing student responses to clicker questions and responses to open-ended questions on the pre/post assessment tests.

d. Lab coordination

- i. The lab for physiology is a one-semester course in which topics from both semesters are covered. To ensure consistency, the lab coordinator met with faculty to build a schedule that aligned with both semesters of the physiology course. In this schedule, students would complete labs that cover the material from the first semester prior to complete labs that cover material from the second semester.

e. 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, two class research projects occurred. These projects required the students to collect their own data over a period of time. These projects were designed to give students exposure to clinical and field-testing, as well as to the data collection and analysis processes.

4. *IPHY –Critical Thinking: Neurobiology of Disease*

a. 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.

b. Developing an Assessment Tool

No specific assessment tool is used. We are assessing whether having students peer review writing assignments help them both identify and summarize key aspects of a primary literature article by analyzing peer review rubric exercises and their final papers in the course.

c. Understanding Student Thinking and Misconceptions

Student difficulties have been identified by close examination of rubric responses in the peer review activities. Also, two mid-term and an end-of-term survey have been given to identify student attitudes to the activities.

d. Class Activities

STF help has guided the development and assessment of the introduction of Calibrated Peer Review into the course.

5. Other courses with some SEI IPHY involvement

Due to interest generated by the department's involvement in the SEI, additional projects have been developed in the following courses:

a. IPHY 2800 Statistics

- i. Examining effect of group-work
- ii. Use of clickers
- iii. Use of a developed assessment tool
- iv. Attitude survey

b. IPHY 3420 Human Nutrition and Performance

- i. Use of clickers.

c. IPHY 4440 Endocrinology

- i. Support on TA training.
- ii. Implementation of concept maps in recitation.

d. IPHY 4650 Exercise Physiology

- i. Support for TA training.

e. IPHY 4720 Neurophysiology

- i. Development of course goals.
- ii. Review of an assessment tool.
- iii. Feedback, modification, and development of clicker questions.
- iv. Feedback and modification of homework activities.
- v. Administration of an end-of-term survey.
- vi. Development and coaching of a research project.

C. Other SEI activities

1. Developing archived resources for faculty
2. Approval for a formal TA training
3. Draft development of manuscript entitled “How Not To Lose your Students in Concept Maps”
4. Creating a SMART classroom for department-wide use
5. CLASS (Colorado Learning Attitudes about Science Survey) – a new tool to assess student beliefs about biology and learning biology.
6. Two members of the IPHY faculty were accepted to the Presidents Teaching and Collaborative, Carnegie Foundation Program. STFs serve as coaches for these faculty.

D. Departmental faculty development and involvement in SEI efforts

1. Faculty involved in leading SEI efforts: Dale Mood (Jan. 2006-Aug. 2008), Bill Byrnes (Aug. 2008-present).
2. Faculty input through interviews/feedback on goals, assessment questions, etc.
David Allen, Roger Enoka, Janet Casagrand, Monika Fleshner, Dale Mood, David Norris, Kenneth Wright, Rodger Kram, Owen Murphy, Adam Hayes, Christopher Lowry, Pei-San Tsai, Ruth Heisler, Steve Hobbs, Bob Hermanson
3. Faculty Partnering with SEI STFs:
Spring 2008: Kenneth Wright, Cynthia Carey, Dale Mood, Bill Byrnes, Ruth Heisler
Fall 2008: Bill Byrnes, Ruth Heisler, Steve Hobbs, Leif Saul, Janet Casagrand, Dale Mood

E. Goals for 2009

1. Finalize learning goals for PHYS II. Continued development of a pre/post-assessment tool, homework, and clicker questions for this course. Providing feedback for exam questions.
2. Finalize the PHYS I assessment tool for measuring student learning. Publish in the *Advances of Physiology Journal*.
3. Finalize the Anatomy assessment tool for publication.
4. Continue to modify and improve homework assignments for primary courses in the department.
5. Creation of Simulation Modules for Neurophysiology.
6. Assist PHYS I faculty with prepared for learning activities (similar to homework).
7. Continue to support faculty efforts in upper-division courses.
8. Publish manuscript on “How Not to Lose Your Students in Concept Maps”.

9. Finalize manuscript for experiment in IPHY 2800 (Statistics) that investigated if the method of assigning students to group work affects student learning.
10. Analyze and publish results of Bio-CLASS survey.
11. Analyze and publish results of Calibrated Peer Review study.

VIII. SEI in MCDB

A. Departmental structure of the SEI program

The departmental structure of the SEI program is unchanged. 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.

B. Course-related efforts

1. General

Working with course instructors for the six large core MCDB courses required for majors, Jia Shi, Michelle Smith, and Bill Wood completed work begun in the previous year to develop course- and topic-level learning goals for these courses. As detailed below, work progressed throughout the year on development of assessment instruments to measure student learning gains, creation of classroom activities, and archiving of these materials. The current state of course transformations for MCDB is summarized on the spreadsheet at the end of this report.

2. MCDB 1041

Fundamentals of Human Genetics is offered every fall, taught by Dr. Jenny Knight. The typical enrollment is between 70-90 students. This is a course for non-majors that fulfills the Arts and Sciences distribution requirement for science.

a. Development of learning goals for the course

The course level learning goals for this course were developed in conjunction with the learning goals for MCDB 2150 (see below). Topic learning goals were developed by Jenny, and differ only in their detail from the topic goals for the main genetics course. In addition, this course has a section at the end devoted to applications of genetics such as biotechnology, the immune system, and cancer.

b. Development of a pre/post genetics assessment to measure student learning

The Genetics Concept Assessment (GCA) developed by Drs. Michelle Smith, William Wood, and Jenny Knight was recently published in a peer-reviewed biology education journal (Smith *et al.*, 2008a). See details in the MCDB 2150 section.

c. Research project (Jenny Knight and Michelle Smith). Do non-majors learn genetics at a different rate than majors? What factors affect how students think about and learn difficult genetics concepts?

Since the non-majors and majors Genetics courses use the same learning goals, they provide an ideal opportunity to investigate whether non-majors and majors are different in how and the level to which they learn genetics. To address these

questions, Michelle and Jenny designed questions to be administered to both classes at three different points in the semester: immediately after common activities that addressed important course goals, on in-class exams, and at the beginning and end of the semester (pre/post). These data points will allow us to compare the content knowledge of the non-majors and majors.

With most of the data analyzed, we are able to determine that students in both the majors and non-majors courses make steady improvement during the courses. Students in the majors course perform significantly better on a few but not all questions relating to specific learning goals. In addition to the content knowledge, we also sought to analyze similarities and differences in how students in these two courses approach learning genetics. We administered surveys to address issues of perceptions about biology, the process of learning genetics, time spent studying, and importance of the class to the students. The most notable differences are: majors spend more time studying for exams, feel that genetics is more important to their future career, and are less likely to blindly trust a peer's opinion on a genetics problem. We anticipate being able to submit a manuscript on this data by April '09.

3. *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. Dr. Quentin Vincens taught an additional small section of this course for the Baker Residence Hall Program (20 students). The same learning goals but different course materials (lectures, problem sets and exams) were used in the two classes. Drs. Jia Shi (STF) and Nancy Guild worked on the co-seminar that accompanies this introductory biology course (see more information below).

a. Development of learning goals for the course

A common set of course and topic learning goals were agreed upon for MCDB1150 course and another introductory course (MCDB 1111) taught by Dr. Mike Klymkowsky. Drs. Martin, Guild and Klymkowsky used these learning goals to design their courses and develop appropriate assessments.

b. Development of an assessment instrument to measuring student learning

Significant changes were made to the Introductory Biology pre/post concept assessment. This change was necessary to align the assessment to the revised course learning goals. About half of the previous Introductory Biology pre/post concept assessment questions used in fall 2007 were modified or re-written. Jia Shi conducted student interviews (n=13) during the summer 2008. These interviews helped reworded questions that include scientific jargon and provided better distracters for incorrect answers. Drs. Jia Shi, Jenny Knight, Bill Wood, Jennifer Martin and Nancy Guild rewrote the questions that are in the current Intro concept assessment. This fall, the updated assessment was given to students in MCDB 1150 (both the large and small classes), as well as at two other institutions. We will be analyzing scores and learning gains from all courses in which the assessment was used as part of preparing a manuscript for publication on this assessment

c. Developing resources for faculty

During the summer of 2008, Jia Shi, with the help of an undergraduate student, organized all Intro biology course materials (learning goals, lecture notes, clicker questions, homework and activities for the optional voluntary study groups) and entered these materials into the UBC archiving system. This archive will serve as a repository for organizing and retrieving all course materials for instructors. We will continue adding to and updating course materials in the archive, which will be available to all current and future instructors in the introductory course.

4. MCDB 1152

Based on data showing the success of voluntary study groups in both MCDB 1150 and MCDB 2150 in fall '07, our departmental faculty unanimously voted to add a voluntary one-credit co-seminar course led by undergraduate learning assistants (LAs) to accompany MCDB 1150 and MCDB 2150 for fall '08. About half of each class signed up for the co-seminar. For 1152 (the co-seminar associated with 1150), Jia Shi worked with Nancy Guild to develop materials, which included concept maps, group activities, and quizzes all focused on difficult concepts in the lecture course. For 2152 (the co-seminar associated with 2150), Michelle Smith and Jenny Knight revised and developed new group activities. LAs were instructed in pedagogy and content before leading their sessions. Most activities involved problem solving; some also involved hands-on manipulations (i.e., chromosome models), and quizzes were given at the end of each activity to measure student learning. Students in both courses rated the co-seminar highly and felt that it helped them better understand the material in the lecture portion of the course. The genetics co-seminar will be offered again in spring '09; the Intro seminar will be offered again in fall '09.

5. MCDB 2150

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 Tin Tin Su taught the class during the spring '08 semester, and Dr. Ken Krauter taught the course this fall. Dr. Michelle Smith (STF) started working with this course in January 2007.

a. Development of course learning goals

A common set of course and topic learning goals were agreed upon for MCDB2150 course. Both Drs. Su and Krauter used these learning goals to design their courses.

b. Development of a pre/post genetics assessment to measure student learning

The Genetics Concept Assessment (GCA) developed by Drs. Michelle Smith, Bill Wood, and Jenny Knight was recently published in a peer-reviewed biology education journal (Smith *et al.*, 2008). The table below summarizes the steps used to develop the GCA.

Table 1. Overview of the GCA development process

Multi-step process used to develop the GCA
<ol style="list-style-type: none">1. Review literature on common misconceptions in genetics2. Interview faculty who teach genetics, and develop a set of learning goals that most instructors would consider vital to the understanding of genetics3. Develop and administer a pilot assessment based on known and perceived misconceptions4. Reword jargon, replace distracters with student supplied incorrect answers, and rewrite questions answered correctly by >70% of students on the pre-test5. Validate and revise the GCA through 33 student interviews and input from 10 genetics faculty experts at several institutions6. Give current version of the GCA to a total of 607 students in both majors and non-majors genetics courses at three different institutions7. Evaluate the GCA by measuring item difficulty, item discrimination, and reliability

The GCA was used as a pre/post assessment to measure learning gains in the CU genetics courses. The GCA is also currently being used at 12 different institutions, and we have received several requests from additional faculty interested in using this assessment in the future.

c. Why peer discussion improves student performance on in-class concept questions

When students answer an in-class conceptual question individually using clickers, discuss it with their neighbors, and then re-vote on the same question, the percentage of correct answers typically increases. It is generally assumed that active engagement of students during discussion with peers, some of whom know the correct answer, leads to increased conceptual understanding, resulting in improved performance. However, there is an alternative explanation: that students do not in fact learn from the discussion, but simply choose the answer most strongly supported by neighbors they perceive to be knowledgeable. In Dr. Su's undergraduate genetics course, we sought to distinguish these alternatives, using an additional, similar clicker question that students answered individually to test for gains in understanding. Our results have just been published in *Science* (Smith *et al.*, 2009). To our knowledge, this is the first time an article on science education was published as a report in *Science*.

The results of our study supported the substantial value of student peer discussion as an effective means of active learning in a lecture class. We presented new evidence showing that an increase in the number of correct answers after peer discussion results primarily from student gains in conceptual understanding rather than simply from peer influence. Previous explanations for the value of peer instruction during clicker questions have maintained the "transmissionist" view that during discussion, students who know the right answer are explaining the correct

reasoning to their less knowledgeable peers, who consequently improve their performance on the re-vote. We found that even students in naïve groups where no one knows the correct answer improve their performance following discussion, which suggests a more constructivist explanation: that these students are arriving at conceptual understanding on their own, through the process of group discussion and debate.

Some instructors who use clicker questions skip peer discussion entirely, believing that instructor explanation of the correct reasoning will be more clear and accurate than an explanation by peers, and will therefore lead to more student learning.

In Dr. Krauter's genetics course this fall we expanded this study to directly compare the benefits of peer discussion, instructor explanation, and a combination of peer and instructor explanation during clicker questions. We found that all three methods result in similar gains in learning. However, the combination method was more likely to help students who initially did not understand a concept. We plan to submit these results for publication during the spring 2009 semester.

d. Developing resources for the faculty

Michelle Smith is finalizing a genetics clicker, homework, and exam question bank. These questions are aimed at targeting widespread student misunderstandings and focus on the analysis of published data. The question bank will be available to all current and future genetics instructors.

6. MCDB 3120

Cell Biology (MCDB3120) is offered both fall and spring semesters. 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 '08 semester and Drs. Greg Odorizzi and Gia Voeltz taught the course this fall. Dr. Jia Shi started working with this course in January 2008.

a. Development of learning goals for the course

A common set of course and topic learning goals were agreed upon for MCDB 3120 course during the summer of 2008. Drs. Greg Odorizzi and Gia Voeltz used these learning goals to design their course.

b. Development of an assessment instrument to measuring student learning

Dr. Jia Shi composed 10 pop quizzes for the spring Cell Biology course. She then derived some assessment questions aligned with the course learning goals based on student difficulties and misconceptions from these quizzes, exams, as well as from student interviews (n=5). Jia will seek feedback from the faculty members who teach the course, conduct more student interviews, and will work with Drs. Jenny Knight and Bill Wood on refining this assessment. A first version of this assessment will be used to measure student learning gains in the spring '09 Cell Biology course.

c. Addition of in-class concept questions using clickers

Drs. Greg Odorizzi and Gia Voeltz used clicker questions in their classroom for the first time in the fall '08 semester. Jia helped both to give feedback on the instructors' clicker questions, as well as write additional questions. With the encouragement of Jia, the instructors improved their clicker questions, writing more conceptual questions as the semester progressed, and ultimately used clicker questions as a review for the final exam.

d. Developing resources for the faculty

Jia is finalizing a Cell Biology clicker and exam question bank. These questions are aimed at targeting widespread student misunderstandings and difficulties. This question bank will be available to all current and future Cell biology instructors.

C. Departmental faculty development and involvement in SEI efforts.

The number of faculty working with the SEI staff continues to increase. Drs. Bob Poyton, Gia Voeltz and Greg Odorizzi all worked with Jia Shi over the past year to begin changing the Cell Biology course. Tin Tin Su generated the idea for and was senior author on the clicker study published in Science. Ken Krauter continued his involvement from last year, and participated in an extension of the clicker study. Dr. Jens Lykke-Anderson has already begun working with Michelle on the spring 2009 molecular biology course (MCDB 3500).

Bill Wood offered the Teaching and Learning Seminar in spring '08 (MCDB 6440), and this seminar will be offered again by Bill and Jenny in spring '09. Bill also presented the work of the SEI, the development of the GCA, and the study on peer discussion in seminars at Univ. of Wisconsin, Madison and Univ. of British Columbia, Canada as well as in the education poster session at the annual meeting of the American Society for Cell Biology.

Michelle Smith was invited to Hong Kong University in summer 2008 to give a presentation on her research and a workshop on writing effective clicker questions. She also presented her research at the CU Boulder Colorado Learning and Teaching with Technology Conference.

D. Goals for 2009

1. General:

- a. The SEI group will be working on writing and publishing at least three papers in the next year, in addition to the two already published.
- b. The working group we organized last year has not been continued due to scheduling issues and a general lack of participation. We will try to rejuvenate this group in 2009.
- c. The STFs have archived their work on MCDB 1041, 1150 and 2150, and will continue to archive their work on MCDB 3120 and 3500 for use by future faculty. An additional course (MCDB 4650), which Jenny and Bill have worked on for several years, has also been archived.

2. Assignments for Jia Shi in 2008
 - a. Finalize the group work paper (see publications in progress below) in spring 2009 and submit the paper for the summer issue of CBE-Life Sciences Education.
 - b. Write and submit Intro biology concept assessment paper in the spring, 2009.
 - c. Work with three teaching faculty during 2009. Dr. Robert Poyton will be teaching Cell Biology 3120 (Spring 09) and Drs. Greg Odorizzi and Gia Voeltz will be teaching the same course (Fall 09). Revise pre/post assessment for this course. Administer pre/post concept assessment. Write homework and clicker questions.
3. Assignments for Michelle Smith in 2008
 - a. Write paper comparing the benefits of instructor and peer explanation during clicker questions.
 - b. Work with Jenny Knight to write paper comparing learning in majors and non-majors genetics.
 - c. Work with Dr. Jens Lykke-Anderson, who will be teaching Molecular Biology 3500 (Spring 09). Develop a pre/post assessment for this course. Write homework and clicker questions.
 - d. Provide limited support to the Principles of Genetics course (MCDB2150) and the accompanying co-seminar.
4. Publications and manuscripts in preparation
 - a. Smith, MK, Wood WB, and Knight, JK. (2008). The Genetics Concept Assessment: A New Concept Inventory for Gauging Student Understanding of Genetics. *CBE Life Sci. Educ.* 7, 422-430.
 - b. 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.
 - c. Shi, J, Knight, JK, Martin, M, Guild, NA, Vincens, Q and Wood, BW. Small group work enhances student learning in a large lecture-based Introduction to Cell and Molecular Biology Course. To be submitted to CBE-Life Sci Educ in spring 2009.

IX. SEI in Physics

A. Departmental structure of the SEI program

The Physics Department was funded by SEI in Spring 2007. The intent of the proposal is to try to extend physics education research-based teaching methods into upper division physics curriculum for majors. Two Science Teaching Fellows have been hired by the department to support this work. Dr. Stephanie Chasteen started Fall 2007 and Dr. Steve Goldhaber started Summer 2008. 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.

B. Course-related efforts

1. 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.

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 – Olive deWolfe (non-PER)

We have now completed the 2nd phase of this schedule.

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. The course was run using interactive lecture technique in-class. Over the course of this term, a bank of clicker questions, kinesthetic, and white-boarding activities were developed for the use of future faculty along with annotations about the effectiveness of these questions/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 1-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.

b. Course Materials

In Fall and Summer of 2008 a set of course materials were developed and organized for future use by Steven Pollock and Stephanie Chasteen. 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.
- 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.
- PUBLICATIONS on this work, including two posters and a conference paper at the American Association of Physics Teachers (AAPT) and the Physics Education Research Conference (PERC).
- 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.

^{**} Indicates materials which have been substantially revised or contributed to in Fall 2008 by Michael Dubson and Edward Kinney.

The course archive materials were made available online and promoted at the AAPT and PERC meetings and met with considerable interest. Several universities indicated interest in our materials, including: Loyola College, Keene State College, Colorado State University at Pueblo, Universidad Santa Maria in Chile, California State University at San Marcos, University of North Carolina, University of California at Berkeley, Augsburg College, Eastern Michigan University, University of Colorado at Denver, Grinnell College, Oregon State University, University of British Columbia, Coastal Carolina University, Brigham Young University, Colorado School of Mines, University of North Dakota, Swarthmore College, Kansas State, Southwestern Oklahoma State, Creighton University, Dublin City University in Ireland, University of Windsor in Canada, and Central Oregon Community College, although not every institution did use the materials. The 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.

Overall reactions to the organization of the materials was positive, though preliminary interviews with Michael Dubson and Edward Kinney suggest that teaching by using established materials can take additional time, rather than saving time, when teaching the course due to the attention required in consulting and adapting previously generated materials.

The four instructors were interviewed individually for one hour, twice during the course of the semester. This allowed us to assess the efficacy of our method of course transformation, sustainability of the reforms, and incorporate suggested changes into the course transformation materials. The results of those interviews are in the process of being evaluated. Instructors using our materials at other universities will also be given a short survey on their usage of those materials, again allowing us to improve them (and/or their formatting and organization) for the future.

Most course materials were developed in Spring 2008, but many of them (namely homework and tutorials) were revised substantially in Fall 2008. All materials were based on detailed student interviews, which occurred biweekly in Spring 2008 and sporadically in Fall 2008, as well as detailed lecture observations.

c. Colorado Upper-Division Electrostatics (CUE) Assessment

The CUE is an open-ended assessment developed based on faculty learning goals. It is a 17-question test consisting of written explanations, conceptual reasoning, sketching, graphing, and a few multiple choice questions. A detailed grading rubric was developed, along with classification of common student errors. 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.

The CUE post-test was given to 3 semesters of E&M I students – Fall 2007 (taught traditionally), Spring 2008 (taught using transformations), and Fall 2008 (second iteration of transformations). The CUE post-test was also given at four outside institutions (Grinnell College, University of British Columbia, Eastern Michigan University, and Rose-Hulman Institute of Technology).

The CUE pre-test was given to 1 semester of E&M I students at CU (Fall 2008), as well as three outside institutions (Eastern Michigan, Grinnell College, and Oregon State University).

The CUE is a reliable and valid instrument – it has been validated through think-aloud interviews. The 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. In the first iteration of the transformed class (Spring 2008), students scored significantly higher on the CUE than in the traditionally taught class (Fall 2007). In the second iteration of the transformations (Fall 2008), however, this does not appear to be the case, and test scores have returned to the level of the traditionally taught course. These results are preliminary, however, and work is ongoing to ensure that grading across all semesters has been consistent. Scores from other universities are in the process of being calculated.

This work will enable 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.

d. Course Data

A traditionally taught course (Fall 2007) and the transformed course (Spring 2008) were compared on several measures to assess the impact of the transformations. Students in the two courses were similar in terms of incoming GPA, ethnicity, gender balance, and college. 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)

Homework scores in the two courses did not differ, due perhaps to the highly collaborative nature of homework, making it a valuable part of the learning process but a less valuable form of assessment. We are interested in learning whether homework scores and course grades are affected by attendance at weekly homework help sessions and/or tutorials, to estimate the pedagogical value of these sessions, and are currently using a multiple regression model to assess how well attendance at tutorials and recitations predict student scores in the course.

The Basic Electricity and Magnetism Assessment (BEMA) has been given to students in PHYS 3310 at the end of the course for the past three 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. In Fall 2008 we saw no evidence that the transformed course structure affected student achievement on the BEMA, similar to previous studies. Concepts on the BEMA are not addressed in PHYS3310 and so student difficulties with this material are not being explicitly addressed in the course. However, new data also shows a substantial (35%) increase in student scores on the sections of the BEMA that are directly relevant to 3310, over the course of the semester. This work is ongoing.

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 course which was not present in the next iteration (Fall 2008), perhaps due to a different student body or a class size that was twice as large. These effects are under investigation, as well as other data on differences between the first and second iteration of the course, 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.

Graduates were employed in a wide variety of jobs, especially in industry and finance. Fewer continued on to graduate school than had been expected. Many recurrent themes were noted with respect to upper-division E&M and Quantum, such as a focus on mathematics at the expense of conceptual understanding, and a disconnect from real-world examples.

These results provide useful information about our graduates and their attitudes as we transform the upper division courses.

2. Quantum Mechanics I (PHYS 3220)

Quantum Mechanics 1, PHYS 3220, is required for completion of the BA in Physics and Astrophysics as well as for the BS in Engineering Physics – about 72% of the course is populated by these majors. The remaining students are comprised of mathematics majors (10%), other natural science majors (2%), non-physics engineering majors (11%) and other miscellaneous and undeclared majors (5%). Typically, this course is taken by juniors and seniors, and the enrollment is 30-50 students. Several faculty have taught this course – in the past five years. Recent instructors have been Eric Zimmerman, James Shepard, John Price, (twice), Tom DeGrand (twice), Kevin Stenson, Michael Dubson, Oliver DeWolfe, and Steven Pollock. For the Spring 2008 semester, the course was taught by Michael Dubson. In the Fall 2008 semester, the course was team taught by Steven Pollock and Oliver DeWolfe. STF Steve Goldhaber started working on this course in Fall 2008.

In Spring 2009 Oliver DeWolfe will teach the course, using the reforms which were developed over the last two semesters.

Ongoing activities include:

a. Developing learning goals

Working in close conjunction with the faculty working group and input from individual faculty interviews, STF Steve Goldhaber has drafted course-scale and subject-

scale learning goals for PHYS 3220. While some of these goals have met with general agreement, there is substantial disagreement in two broad categories.

The first category has to do with the scope of the class. For instance, several faculty members feel strongly that PHYS 3220 should include addition of angular momentum including the use of Clebsch-Gordan coefficients while others feel (just as strongly) that teaching this subject would overload an already challenging class. Other subjects with similar (although less strenuous objections) are scattering and wave packets. Currently, none of these subjects are listed as subject learning goals although this affects the second semester course.

The second category is more related to the philosophy of how to approach the teaching of quantum mechanics. Some faculty members feel that students should first master classical mechanics at the level of Poisson bracket before delving into quantum mechanics. Others feel that learning about commutators and the meaning of the Hamiltonian is an appropriate starting place. Similarly, some faculty members feel strongly that emphasizing two-state systems and matrix methods represents a better pedagogical approach than the approach used by Griffiths. While these differences are important, they do not affect the learning goals for the course.

b. Changes in course instruction

The course run in Spring 2008 by Michael Dubson was transformed to use an interactive lecture style in class. Over the course of this term, a bank of clicker questions were developed for the use of future faculty along with annotations about the effectiveness of these questions/activities. In addition, many new homework questions were developed, avoiding the issue that solutions to all of the homework problems in the standard text are available online.

In Fall 2008, Steve Pollock and Oliver DeWolfe team taught this course and built upon the work started by Dubson. In addition to incorporating clicker questions and white-boarding activities into the class, Pollock and DeWolfe incorporated additional reforms. Optional tutorials were incorporated into the course to give students a chance to struggle with some of the underlying conceptual ideas as a basis for the more standard quantum homework. Five of these tutorials were from the University of Washington, two more were a blend of material from the University of Washington and material developed by Steve Pollock, two were developed by Steve Pollock and two were a result of collaboration between Steve Pollock and Steve Goldhaber. These tutorial sessions have since been institutionalized as optional 1-credit co-seminar courses which do not count towards the major. In addition, Pollock and DeWolfe revised the homeworks 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. In connection with these homeworks, biweekly group problem solving sessions were run to allow students to work through homeworks in a group setting.

c. Interviews with faculty

Steve Goldhaber interviewed six faculty members who have previously taught PHYS 3220 and/or the second-semester course PHYS 4410, and has spoken extensively with the current instructors (Pollock and DeWolfe). Some of the key issues raised by faculty are listed below:

- There is wide concern over the issue of continuity between PHYS 3220 and PHYS 4410. Several faculty expressed the desire of having a single faculty member teach the two semesters in sequence. A larger group is concerned that the lack of definition of the subjects to be included in PHYS 3220 makes it more difficult to plan a semester of teaching PHYS 4410 because information on where they must begin is usually not available before the end of the previous semester.
- Almost every faculty member interviewed for this project expressed concern over the level of mathematical sophistication and problem-solving ability of the students taking PHYS 3220. There is a lot of uncertainty as to exactly what mathematical preparation is to be expected.
- Several faculty members expressed dissatisfaction with students training in classical mechanics prior to taking quantum mechanics. Two subjects frequently mentioned are classical Hamiltonian dynamics (including, *e.g.* the Poisson bracket) and classical wave physics.

d. Developing an assessment instrument for measuring student learning

With the assistance of several faculty members, Steve Goldhaber has developed a post-test assessment tool based on the learning goals, and has performed preliminary validation of the instrument through interviews with faculty and students. During development of the test, a total of 13 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. 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.

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.

Students in PHYS 3220 were also asked to complete Modern Physics Attitude Survey at the beginning and at the end of the semester. During the fifth week of class, they were also asked to complete a quick survey on workload and pacing. Finally, at the end of the term, they were asked to complete a more extensive 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.

The results from the tests and surveys are being analyzed by the team.

e. Understanding student learning and thinking

To develop an understanding of student thinking and difficulties in the course, Steve Goldhaber observed the regular lectures and ran a weekly homework help session. In addition, Steve ran 10 of 11 weekly tutorial sessions and helped to develop two of the tutorials. These tutorials are intended to help students develop their understanding of areas of the course which tend to be the most challenging.

f. Developing resources for faculty

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 will be chosen and developed to align with the learning goals for the course, allowing faculty to provide students with

assignments that may develop a wider variety of student skills than those that a single faculty can easily create. Similarly, the concept/clicker questions developed for the course will be 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 subject. During the Fall semester, significant work went 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 the answers.

3. Upper-division Labs (PHYS 3330 and 3340)

A substantial number of faculty in the department have indicated a strong interest in working to improve the upper-division laboratory experience for students, and one junior faculty member (Heather Lewandowski) has written her NSF career grant to include this work. Initiated by inquiries on the part of the STFs, a faculty working group has engaged in email conversation and two meetings on the topic. There is a wide discrepancy in faculty opinion on the priorities for this project. The effort is being led by Dr. Lewandowski, with support from the STFs.

In particular, the STFs have assisted with:

- Creating detailed documentation on the structure of upper division labs at a variety of institutions – those similar to CU and those with upper-division labs that have been highly recommended in the physics community
- Gathered materials (e.g., lab descriptions) from the above
- Discussed possible grant funding options with Dr. Lewandowski
- Discussed priorities for lab transformations with Dr. Lewandowski individually, as well as in the faculty working group

C. Departmental faculty development and involvement in SEI efforts.

The faculty working group for E&MI was convened about 4 times this year, to present results from the course transformations and the CUE. Some members of the faculty working group for 3310 were consulted individually as the CUE post-test was revised.

The STFs have presented work several times at faculty meetings, including the overall results from the PHYS 3310 transformations which sparked a discussion of the appropriateness of clickers and tutorials in upper-division courses. STF attendance at faculty meetings has increased the visibility of the SEI program as well as increased casual interaction with faculty.

Dr. Chasteen has worked with Dr. Peter Delamere on adding more interactive components to the follow-up course to 3310 (PHYS 3320), and provided him with materials from other universities. She has also interviewed the four faculty (deWolfe, Pollock, Dubson, and Kinney) on the process of the course transformations. These faculty also participated in a series of working meetings with visiting physics education scholar Joe Redish.

In addition to the private interviews discussed in the previous section, Dr. Goldhaber held three group meetings where faculty discussed learning goals for quantum I (PHYS 3220). A total of thirteen faculty members contributed to these discussions.

D. Goals for 2009

General:

- Present results of alumni survey to faculty and suggest relevant action items for the undergraduate committee based upon the results.
- Encourage conversation between physics and math faculty regarding preparation of students for upper division physics courses
- Support Dr. Lewandowski in upper-division lab reforms.
- 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.
- Offer support to faculty teaching quantum mechanics at other levels. Efforts will include help integrating reformed teaching techniques into PHYS 4410 during the Spring 2009 semester.

Goals for work on 3310:

- Compile and analyze data on 3 semesters of 3310, including tutorial attendance, BEMA, CUE, and attitudinal data. Write 2-3 papers for publication on this work on the CUE, results of course transformations, and regression analysis.
- Observe and record the implementation of the transformations as Dr. Kinney teaches the course on his own. Write a paper on sustainability of course transformations based upon this and faculty interviews throughout the process.
- Work with Dr. Kinney to develop pre- and post- tests for individual tutorials.
- Support smaller-scale transformations in 3320 and other upper-division courses depending on faculty interest.

Goals for work on 3220:

- Improve the post-assessment tool using both further student interviews and work with faculty. Work with faculty will include improving the rubric by assessing independent graders to identify and fix ambiguous entries. Also, more faculty input will be solicited on the usefulness of the tool in assessing student progress in understanding quantum mechanics.
- Obtain wide faculty agreement on learning goals at both course scale and subject scale.
- Continue work on bank of homework, exam, and clicker questions. Prepare material for easy and useful access by future faculty.
- Investigate key areas of student difficulty through student interviews.

- Identify key questions, which will lead to systematic research studies within the course. A topic of particular interest is the apparent lack of success in helping students overcome well-known difficulties in learning quantum mechanics, even with the targeted efforts made during the Fall semester.