Proposal Submitted to NSF-CCLI Program May 2009

Project funded for period 01/01/2010–06/30/2012

Title:

Creating an Academic Community to Foster Curiosity and Discovery in Introductory Geoscience Classes

PIs:
Karen Grove (Project Director; kgrove@sfsu.edu)
Dave Dempsey
Petra Dekens

Department of Geosciences
San Francisco State University
San Francisco, CA 94132

PROJECT SUMMARY

Most students at San Francisco State University (SF State) enroll in an introductory geoscience course (in geology, oceanography, meteorology) to fulfill a physical science general education requirement, but they are fearful of science courses, uncertain about how science works, and doubtful that the courses will have meaning for them. Yet in their daily lives they are bombarded with information and opinion related to scientific issues that they are poorly equipped to interpret. This is usually the only college-level geoscience course that they take, so we have one crucial opportunity to help them learn how the earth operates, how science works, why it is important that they learn these things, and how they can make informed decisions in today's technologically-advanced society.

Students in the laboratory component of our introductory courses want more exciting, hands-on, and relevant materials. In response, the Geosciences Department proposes to mount a focused, sustained effort to create an environment where (a) students in the introductory courses will learn more about both geoscience concepts and the process of science, and where (b) instructors will be better trained to guide the students' learning. Primary project objectives are to:

1. Develop, adapt, and refine engaging, meaningful, and effective lab materials that use a consistent inquiry-based learning (IBL) approach, real-world data, and problems relevant to students, and that attend explicitly to the process of science. Expected outcomes are that students will better understand basic geoscience concepts, how science works, how science relates to their lives, and how to distinguish science from non-science presentations.
2. Build a Geoscience Exploration Laboratory (GEL) where students learn from the lab materials by working in collaborative groups to ask questions, explore data sets, use analytical tools, and discuss and write about their results. The facility will allow us to implement an IBL approach and achieve our desired student-learning outcomes.
3. Create a new Teaching and Learning Community (TLC) to share professional and curricular development efforts, improve instruction, and better connect the lab and lecture courses so they support each other. Expected outcomes are that all project participants, especially the graduate teaching assistants, will be more effective instructors, with greater focus on student learning, and will work in a more supportive environment.

Intellectual merit. Project activities are based on established research about how students learn science. They will employ teaching strategies that effectively engage students in science, help students to learn and retain scientific principles, and guide them to apply and understand the processes of science. The project builds on past innovations of the PIs to improve geoscience courses, including the use of technology to scaffold learning (e.g., Just-in-Time Teaching technique). The project builds on strong support at many levels of the University for improving teaching and learning. An experienced team, including a science education at SF State, has been assembled to assess the outcomes of the project.

Broader impacts. The project will directly impact >500 students/year (in laboratory courses) and will also impact ~1400 more students/year (in lecture courses) at SF State, one of the most ethnically and culturally diverse campuses in the United States. We will extend the impact more broadly by presenting at professional conferences, uploading modules about materials and methods onto teaching and learning web sites, creating manuals of new laboratory materials and marketing them to other geoscience departments, and publishing articles in science education journals. Project activities will serve as a model for geoscience departments elsewhere who want to improve their introductory courses.

PROJECT DESCRIPTION

The Curricular Need—Our Goals and Objectives

A major goal of the general education (GE) physical science program at San Francisco State University (SF State) is to develop in non-scientists an ability to make informed decisions about the scientific and technological issues they encounter and an understanding of the connections between scientific developments and contemporary issues. The GE courses in our Geosciences Department often serve as a first introduction to the geosciences and many of our majors are attracted to our programs through these courses. The majority, though, are simply fulfilling their physical science requirement and these courses may be the only geoscience course (and possibly the only physical science course) they ever take. So we have one crucial opportunity to help them learn how the earth operates, how science works, why it is important that they learn these things, and how they can make informed decisions in today's technologically-advanced society. Through these courses we can impact the learning of many students, most of whom will not become scientists, but all of whom are citizens living in a world where scientific issues abound.

Our GE curriculum includes 13 courses in geology, oceanography, and meteorology; each year 2500–3000 students enroll in these courses. Of that number, >500 students/year enroll in a lecture course and a related but separate laboratory course in our three disciplines: Introduction to Geology (Geol 100/101), Introduction to Meteorology (Metr 100/101) and Introduction to Oceanography (Ocn 100/101); another ~1400 students enroll in the lecture course alone. Our project focus on the laboratory courses will directly impact students enrolled in the 100 and 101 courses and indirectly impact those enrolled in only the lecture (100) courses. We have the potential for even broader impact by providing a model for GE courses elsewhere, particularly in California community colleges and at other campuses in our university system that have similar courses and GE requirements. At the nationwide level, Geoscience enrollments have been low for some time (http://www.agiweb.org/workforce/stats/enroll.html), and there is clearly a need to create models that better spark interest among students.

In the 100/101 courses at SF State, many instructors have developed curricular materials and used innovative teaching methods in their individual classes, but the instructors communicate very little and hence there is little coherence among courses. The lack of coherence between lecture and lab courses is especially acute, largely because tenured and tenure-track faculty and lecturers teach the lecture classes while Graduate Teaching Assistants (GTAs) teach the independent laboratory classes. The lab classes are not attached formally with any particular lecture class, although completion of a lecture class is prerequisite or corequisite. Consequently, there is no requirement (and little opportunity) for the various instructors to coordinate their efforts. Moreover, GTAs receive little guidance about how to teach their lab classes effectively, and some of the materials are ad hoc collections that students have compiled through their own efforts or borrowed from other students with next to no training or feedback. Finally, instructors know little about the University's learning objectives for the introductory courses, which focus entirely on the process of science, and so they make no concerted effort to address them.

A focus group in April 2009, with 12 of the GTAs who teach (or have taught) the introductory geoscience labs, further demonstrates the need for improvement. GTAs are enthusiastic about their positions and they have strong interest in improving their teaching—one indication is that 80% of current graduate students who have worked as GTAs attended the meeting. However, they feel they receive little support in their efforts to gain teaching skill and present interesting labs. They all are dissatisfied with the available lab materials, many of which are out dated and uninspiring, and some GTAs spend considerable time trying to develop their own. They are frustrated by the lack of communication with the lecture instructors and with the lack of connection between lecture and lab courses, as some students in their classes have already been introduced to the topic they are teaching, whereas others have not. They would like to teach more hands-on activities where students conduct experiments and engage in collaborative discussions to apply their results to real-world problems, a process akin to what we as scientists do.

A review of student evaluations from the introductory lab courses during the past 3 years are consistent with the views of their GTAs. The students mostly approve of their GTAs and feel they are enthusiastic about teaching and responsive to their needs. The evaluations of the labs themselves are less positive. Students express strong support for the labs that include field trips or any type of hands-on activity, and satisfaction with topics that connect to their lives or to environmental issues. When asked what should be improved, students request more field trips, more hands-on activities, and more engaging labs that stimulate their interest. They express frustration over boring, out-dated lab materials and activities perceived as busywork. A surprising number of students seek more challenging labs and materials that will help them to learn more. Some say that their lab class connects well with their lecture class, whereas others see little connection.

The Geosciences Department needs a new space where students in the introductory labs can work on inquiry-based activities in collaborative groups, with computers available to access data sets, use analytical tools, and write results. Currently, the department has several computer teaching labs that are generally small in size and overly subscribed by our upper-division courses.

To invigorate our introductory courses and improve teaching and learning in them, we need to mount a focused, sustained effort to create an environment where students in introductory geoscience courses better understand geoscience concepts and how science really works and where instructors are better trained to guide the students' learning—our overarching goal.

Our primary objectives are to:

1. develop, adapt, and refine engaging, meaningful, and effective lab materials that use a consistent inquiry-based learning (IBL) approach, real-world data, and problems relevant to students, and that attend explicitly to the process of science.
2. build a Geoscience Exploration Laboratory (GEL) where students learn from the materials by working in groups to ask questions, explore data sets, use analytical tools, discuss and write about their results.
3. create a new Teaching and Learning Community (TLC) to share professional and curricular development efforts, improve instruction, and better connect the lab and lecture courses so they support each other.

The Development Plan—Our Response to the Need

To improve student learning in our introductory classes, we plan to (1) develop new inquiry-based activities for the laboratory courses; (2) build a new Geoscience Exploration Lab (GEL) where students collaborate to learn how the earth and science work; and (3) create a Teaching and Learning Community (TLC) to focus attention on effective methods that boost student learning. Our first task will be to rename the introductory courses to make them sound like the more interesting courses we expect them to become. The current Introduction to Geology/ Oceanography/Meteorology courses will become: Our Dynamic Earth, Our Dynamic Ocean, and Our Dynamic Atmosphere, to emphasize that these are systems in which the students live and are surrounded by daily. Currently, students enrolled in the laboratory component of these courses are not necessarily enrolled in the lecture component of that course (and students in any lab could be enrolled in lecture sections offered by different instructors). We will change this so that all students enrolled in the lab sections will be enrolled in the same lecture section, thereby providing the opportunity to create a link between lecture and lab that is currently missing. We provide details about the three main project components below (see Project Timeline on page 15 for details about who will do what and when they will do it).

Create new laboratory materials

In most introductory science courses, including ours, the emphasis of the course is on teaching the content knowledge of the given science. This is the only science course most of these students will take during their academic career. For these students, the courses must focus on providing the tools required to evaluate socially-relevant science presented in the media so they can make responsible decisions. For those students who will consider a scientific career, the exclusive focus on content is also a disservice, as a complete understanding of science involves not just the content knowledge, but also an understanding of the process of science, including how scientific knowledge develops and evolves within a scientific culture, and how science influences society (discussion of these issues in Egger, 2009, and references within).

In building new lab activities, the following two objectives must be addressed. First, students must build a content knowledge base in the given discipline that allows them to understand some of the fundamental concepts about how our planet works. Second, we must *explicitly* teach students about the process of science.

As described in the Rationale section below, research shows that students learn best when inquiry-based learning (IBL) methods enable students to build their own knowledge, when subject matter is made relevant to their lives, and when they engage in hands-on activities with other students. We will create new laboratory manuals that use a consistent IBL approach. Students will use real-world data that is publicly available on the web and that they collect in the lab and the field, and they will work with their peers to analyze and interpret that data. Topics will be chosen that relate to students' lives. Examples include California earthquake data, coastal wave and tide data, and weather station data from different Bay Area regions.

Teaching the process of science, along with using IBL methods, is at the heart of our proposed curriculum development, and we will infuse materials with an explicit focus on how science works and what scientists do. Tools like the Visionlearning web site will help us to better incorporate this element. We identify below some of the processes and skills that we expect to include in our activities.

- Working with data, including existing on-line data sets and student observations. Students will analyze and interpret, use mathematical and statistical tools (including uncertainty, error, and confidence), use graphs and visual data, ask questions about the validity of data (importance of quantitative skills in Manduca et al., 2008).
- Using multiple research methods. Students will experiment, observe and describe, use and make models, make quantitative comparisons.

- Working collaboratively. Students will work together to discuss, analyze, and interpret geoscience data.
- Communicating science. Students will record their observations and interpretations and communicate their ideas (e.g., written report, poster presentation, or oral presentation).

To design the labs we will take advantage of the rich collection of available materials that have been previously used and shown to be effective. Many activities from the following resources can be adapted to meet our needs:

- Science Education Resource Center (SERC— http://serc.carleton.edu/index.html). Components include Earth Exploration Toolbook with data sets and analytical tools, Teach the Earth portal for Geoscience faculty, and much more.
- Visionlearning web site with modules about learning science, with emphasis on science as a process (http://www.visionlearning.com/).
- DLESE—Digital Library for Earth Science Education curricular collections (http://www.dlese.org/library/index.jsp)
- Understanding Science—How Science Really Works (http://undsci.berkeley.edu/)—resources about making learning about science explicit

One example of the type of activity we plan to develop is a lab developed by PI Grove for the Introduction to Oceanography Laboratory course. It is the lab most often cited by students and their GTAs as being exciting and promoting learning. It uses the "jig-saw" method and is entitled "What sinks, what rises?" During this lab activity, the class is divided into five groups (1–5). Four groups conduct experiments that involve measuring the density of different materials (rock, fresh and salty water, warm water, and cold water); the fifth group does experiments to illustrate buoyancy. Each group plots their data, describes a relationship (i.e., fits a line to the data to create a model that describes the relationship), considers the uncertainty in their measurements, and interprets their data by answering a series of questions. The students are then re-grouped, this time into Groups A–E, and each group has one member from each of original five groups (the "jigsaw" method). Each member of the new group describes the methods, results, and interpretations from their experiment to members of their new group. The new group members then discuss all of the results and apply what they have learned by answering questions about how density influences oceanic processes.

This lab activity illustrates our goals in a number of ways. Students participate in group activities and are guided through a series of questions that ask them to formulate a hypothesis (e.g., what will happen if you add salty water to fresh water?). The students use various measurement tools (basic math, rulers, refractometers, hydrometers, thermometers, balances), and are asked to consider their measurement uncertainties. They plot their data and create a model that describes that data (a fit curve or line). Finally, the jigsaw method gives students the opportunity to present their results to others, giving them the opportunity to be "experts" and to see how peer collaboration and review works in the scientific process.

As much as possible, we want students to collect their own data, either in the field or in the laboratory. It is not possible to take as many field trips as students would like, but they can still get meaningful, hand-on experiences by working with materials in the lab and by using some of the rich data sets that are available on the web and that they can access using computers in our new Geosciences Exploration Lab (GEL). When students collect their own data, they will use computer tools to analyze, visualize, interpret, synthesize and present.

Build a new Geoscience Exploration Lab (GEL)

Laboratory sessions will be conducted mostly as inquiry-guided activities, in which students work in collaborative groups to access and explore data, ask questions, posit explanations, apply analytical tools, discuss problems and interpretations, and present results. To facilitate an inquiry-based instructional strategy on the scale that we intend, we will need to re-design and equip an existing classroom to become the Geoscience Exploration Lab (GEL).

The room that will become the GEL is currently configured and used mostly for lectures. We will remodel the room to accommodate tables with chairs on rollers so that small groups of people can easily form and face both each other and the front of the room. White boards will be accessible from each table to facilitate discussions. This design is similar to the SCALE-UP environment created at North Carolina State University, which, along with an inquiry-based approach to teaching, has been shown to improve student learning (Oliver-Hoyo and Beichner, 2004). The room will be equipped as a "smart classroom", including a ceiling-mounted computer projector, speakers, DVD player, and a video camera, all accessible to the instructor from the front of the room. The Department of Geosciences and the College of Science and Engineering at SF State have agreed to pay for these renovations (see Dr. Garcia's letter).

One of the most vital components of the GEL will be the installation of networked laptop computers at each table (one laptop per group of two or three students). We expect the GEL computers to support students in most of our inquiry-based lab activities, who will be able to access and engage with computer- and web-based instructional materials; access, display, and analyze data; and share data and communicate ideas and results. One of the co-PIs (Dempsey) currently receives release time from the College of Science and Engineering to administer and maintain the Department's existing computers, and he will assume responsibility for administering the new lab as well.

Create a new Teaching and Learning Community (TLC)

Faculty members, lecturers, graduate teaching assistants (GTAs), and undergraduate peer facilitators (UGPFs) will all be involved in our project as instructors. They will form the core of a teaching and learning community (TLC) involved with professional development activities and promoting effective teaching in our introductory GE courses. TLC participants will interact with others engaged in science education and establish a framework that the Department of Geosciences will continue to support beyond the life of the grant.

During the period funded by the grant, participants in the TLC will interact in several contexts. First, the grant will support three GTAs to enroll in a pair of graduate courses designed for GTAs and other instructors-in-training—Sci 750/850 ("Teaching Science for Scientists I and II"). These courses introduce participants from multiple science disciplines to issues of teaching and learning in the larger context of the science education field.

Second, the three grant-funded GTAs will join the co-PIs, lecturers, and other interested SF State science instructors in a one-day curriculum-development workshop about using real-world data sets for inquiry-based instruction and teaching the process of science. Cathy Manduca (Carleton College, Science Education Research Center—SERC) and Anne Egger (Stanford University) will facilitate the workshop (see their letters of support). During the subsequent weeks, co-PIs and grant-funded GTAs will collaborate to define learning objectives and outcomes for lab activities and develop working drafts of inquiry-based activities for the introductory geosciences labs. Over the life of the grant, we will support two more groups of GTAs—those actively involved in curriculum development—to enroll in Sci 750/850 courses (see Project Timeline).

Third, from the semester in which we implement the inquiry-based lab activities onward, all members of the TLC, including GTAs and UGPFs not involved in curriculum development, will participate in a one-unit graduate seminar course—"Our Dynamic Classroom". The course will provide a forum where participants will share their experiences in the introductory labs, discuss assessment data about lab activities, and engage in a variety of activities related to improving teaching and learning. The Department will institutionalize the course to continue providing geosciences-specific professional development for our GTAs and UGPFs after the period of grant funding ends (see letter of support from Dr. Garcia, Department Chair).

The UGPFs will often be students enrolled in our B.A. in Earth Sciences program, some of whom aspire to become high school or middle school science teachers. In the "Our Dynamic Classroom" seminar, they, along with GTAs, will receive training in small-group facilitation and observation, and will apply those skills in the introductory labs. They will provide valuable assistance in the classroom and help us collect assessment data while getting exposure to teaching as a professional activity.

In addition to providing pedagogical support, the TLC will also ensure a better link between the lecture and lab portions of the course. As part of the "Our Dynamic Classroom" seminar course, the lecturers, GTAs, and UGPFs will split up into their respective disciplines to discuss the details of the lab activity of the previous week and strategies for the lab of the coming week. These detailed discussions will provide one form of assessment of the laboratory activities. But it will also ensure that the instructors for the lecture and the GTAs for the labs are in constant communication, and that the material covered in lecture supports the material covered in the lab in an appropriate sequence.

Expected outcomes

Outcomes we expect to achieve as a result of project activities described above relate to students' learning about geoscience concepts and the process of science, and their attitudes toward science. Outcomes also relate to TLC participants' teaching effectiveness and their attitudes about teaching, and to the larger impact of our TLC experience. More specifically, our expected outcomes will be:

4. Students will better understand how science works, how to use multiple methods, how science relates to their lives, and how to distinguish science from non-science presentations.
5. Students will better understand basic geoscience concepts.
6. Students will like geoscience (and science overall) more.
7. All project participants, especially the GTAs, will be more effective instructors.
8. All project participants, especially the GTAs, will be working in a more supportive environment.
9. Undergraduate students, particularly those interested in a teaching career, will gain pedagogical knowledge and teaching skills by working as peer facilitators
10. Geosciences instructors will achieve greater focus on student learning
11. Project activities will serve as a model for other geoscience departments/courses elsewhere.

The Rationale—Why the Plan will Achieve our Objectives

We expect to achieve our objectives because of the project's ***intellectual merit*** and its ***broader impacts***. The project is meritorious because it builds on established research in science, more generally, and in geoscience, more specifically, about how students learn. It also builds on past PI innovations and on the strong support that is available at SF State for improving the teaching and learning environment. The project's influence will be broad because it will directly impact >500 students/year at SF State, many from groups underrepresented in the geosciences, and it will indirectly impact many more in the department, university, state, and beyond.

Builds on research about how students learn

The science education literature will inform almost every aspect of our efforts to improve student learning in our introductory geosciences courses and to provide professional development for our instructors. Here we highlight insights from constructivist theory and studies of content knowledge and misconceptions, inquiry-based learning (IBL), collaborative learning, student motivation, and instructional technology.

Over the last several decades, researchers studying science education have begun to advocate for a constructivist approach to classroom instruction. This approach, developed by cognitive psychologists during the mid 20th century, focuses on student learning rather than on the process of teaching (see a history and basic principles of constructivism in Mintzes et al., 1997). Constructivism asserts that to truly learn something, students must actively construct their own knowledge rather than passively receive knowledge transferred from others or acquired by rote memorization (Mintzes et al., 1997).

Research about how people learn indicates that learning is enhanced when the learner experiences concepts and principles in multiple contexts and synthesizes the deep principles underlying the knowledge learned (Etkina and Mestre, 2004). The constructivist view is aware that "the single most important factor influencing learning is what the learner already knows" (Mintzes et al., 1997) and points out that ignoring a learner's prior knowledge makes it more likely that the message intended by the instructor will not be the message understood by the student (Etkina and Mestre, 2004). To overcome the tendency of learners to cling to past knowledge and to help them construct new scientific knowledge, learners need to practice processes similar to those used by scientists to construct knowledge (e.g., observing natural phenomena; classifying, recording, and identifying patterns; devising models to explain patterns; designing experiments to test explanations) (Etkina and Mestre, 2004). Adopting a consistent approach in all of our labs that incorporates real-world data and the same processes of inquiry that scientists use, and applying basic principles repeatedly in multiple contexts, will begin to break down students' misconceptions and give them the motivation and confidence to construct new knowledge for themselves.

From the constructivist perspective, our plan to redesign laboratory activities to become hands-on, inquiry-based, and cognizant of prior student conceptions, and to ask students to revisit concepts and reapply concepts and skills in multiple contexts, should improve student learning.

Research in introductory science courses has also shown that students learn best when they feel that the subject matter relates to their lives and when they engage in hands-on activities in collaborative groups with other students, with the instructor serving as a learning coach (e.g., King, 1993; Johnson et al., 1998; McDonnell et al., 2005; Etkina and Mestre, 2007). Our proposed renovations of a classroom to create the GEL (see earlier section, “Creating the Geoscience Exploration Lab”) will provide a classroom environment that facilitates interactions within collaborative groups working on geoscientific problems. We are fortunate to have a multidisciplinary department where we can draw upon the expertise of our faculty in geology, oceanography, and meteorology to create lab activities on topics meaningful to students. Earth system science research and new advances in technology provide real-world data about global climate, natural hazards, and other topics of pressing social significance (Bralower et al., 2008) that we can leverage to motivate students to learn more about the principles and approaches of the geosciences.

Other sciences, especially physics, have long applied cognitive research to understanding student preconceptions and how instruction can be designed to change them (e.g., Champagne et al., 1982). Fortunately, geoscience educators have recently begun conducting this type of research as well, and we now have new tools to help us design more effective learning materials. For example, Libarkin and Anderson (2005) developed a Geoscience Concept Inventory (GCI) and administered it pre- and post-course to students in 43 introductory geoscience courses at 32 institutions in 22 states. Results showed some improvement in students’ conceptual understanding, with most gains for low-performing students (i.e., those with the lowest pre-test scores). More recently, Petcovic and Ruhf (2008) used the GCI to test pre- and post-course conceptual knowledge of students enrolled in Earth Science for Elementary Educators. Like Libarkin and Anderson (2005), they found that some pre-existing ideas were entrenched and difficult to change (e.g., radiometric dating and earth time). They saw the largest conceptual gains when topics were not covered solely by classroom discussions and homework assignments but that also held particular interest for the students and where students were asked to share prior knowledge, manipulate models or data related to the content, work collaboratively to reach conclusions, and reflect further on the content they had learned (Petcovic and Ruhf, 2008). Anderson and Libarkin (2008), updating their own earlier work, analyzed GCI pre- and post-course scores in introductory geosciences courses at over 50 institutions and found little or no gain in scores on most questions. We interpret their results to support the importance of learning the same concepts and practicing science process skills in multiple contexts, even at the expense of broader content coverage.

McDonnell et al. (2005) applied methods from developmental psychology to assess connections between logical thinking skills and student grades in introductory geoscience courses. They noted studies showing that about half of early college students think at the “concrete” operational stage, whereas college courses require them to think abstractly. Concrete operational thinkers advanced their level of thinking the most when instructors introduced concepts using concrete examples drawn from students’ experience, then not only engaged these students in challenging IBL exercises requiring higher-order thinking skills but did so in structured, small-group collaborations with intellectually more sophisticated peers. The CSU system does not draw many of the top-tier students from high school, so many of our students need remedial coursework and it is likely that a high proportion of students in our introductory courses are concrete operational thinkers. Hence, the work of McDonnell et al. (2005) should inform our efforts.

Bransford et al. (1999) summarized important ways in which instructional technology can, if used appropriately, enhance learning. It can help to bring exciting activities based on real-world problems into the classroom; provide scaffolds and tools to enhance learning; give students and teachers more opportunities for feedback, reflection, and revision; and build communities of teachers and learners. The Geosciences Exploration Lab (GEL) that we propose to build, equipped with networked laptop computers, will allow us to exploit many of these benefits.

Builds on past innovations by the PIs

The proposed project builds on previous innovations of the three PIs, all of whom have a strong commitment to improving scientific education, both at the general education and upper division levels, as demonstrated by their previous contributions and ongoing work.

PIs Dempsey and Grove have collaborated on the development of several courses using innovative pedagogical approaches. In 2000, they received a grant from the NASA-NOVA program to create "Planetary Climate Change", an interdisciplinary geosciences course for pre-service secondary science teachers and geosciences majors (http://funnel.sfsu.edu/courses/gmo405) (Dempsey, 2001; 2002). They were also co-PI's on a NSF-CCLI grant in 2002 and created an integrated, standards-based geosciences course for pre-service K–5 teachers—"Investigating Land, Sea, and Air Interactions" (http://funnel.sfsu.edu/courses/gm309). Both courses are student centered; "Planetary Climate Change" employs an inquiry-based pedagogical strategy (Dempsey et al., 2000), while "Investigating Land, Sea, and Air Interactions" implements a problem-based learning pedagogical strategy in which students work in small groups on practical problems of local geology, oceanography, and meteorology (Dempsey and Quita, 2004). Both courses make extensive use of computer-based instructional technologies where students are required to access, display, and analyze global datasets (Dempsey, 2003). PI Dekens has more recently become involved in these efforts as a co-instructor for "Planetary Climate Change".

Both PIs Grove and Dempsey have experience setting up and maintaining small computer labs for student use. PI Grove's 1995 NSF-ILI grant created the Earth Systems [computer] Laboratory (ESL), dedicated to the visualization and analysis of earth features to improve the laboratory component of the Introduction to Oceanography course. She created online activities that continue to be used at SF State and other institutions (http://geosci.sfsu.edu/courses/geol103/labs/labs.html), as well as a laboratory manual (now out dated) that focuses on local problems. PI Dempsey established a computer-teaching lab for the Department of Geosciences Meteorology program with a 1994 NSF-ILI grant. He installed software to acquire a continuous stream of real-time weather data via the internet, then developed software to generate weather maps and images from the data, which have been integrated into the Meteorology curriculum and made publicly available through the popular California Regional Weather Server (CRWS) (http://virga.sfsu.edu).

PI Dempsey was instrumental in creating the Center for Science and Mathematics Education (CSME) at SF State, and he has served as a faculty associate director since its inception. CSME strives to recruit, support, and develop pre-service K–12 science/math teachers and foster science/math education research and its application to practice (see Dr. Ozer's letter of support).

All three PIs have attended numerous workshops that have helped them improve their courses. After attending a 1998 NSF-NAGT workshop on "Innovative Teaching Methods in the Introductory Geosciences", PI Grove created "Virtual Voyages" that require students to complete online homework assignments prior to attending class. These "Virtual Voyages" help prepare students for class by having them examine imagery about a topic prior to attending class, thus creating a more discovery-based learning environment (Grove, 1998; 2001; 2002; http://geosci.sfsu.edu/courses/geol102/home.html). More recently, she applied this technique, now called Just-in-Time Teaching (JiTT), in her Introduction to Geology course, and was the subject of a video case study prepared for the CSU teaching/learning web site Merlot/Elixr (http://pachyderm.cdl.edu/elixr-stories/serc-geoscience/). PI Dekens attended a Cutting Edge workshop on "Teaching Introductory Geoscience Courses in the 21st Century", after which she incorporated student-response systems "clickers" in her large lecture course to improve student learning by encouraging their regular review of the material and to get immediate student assessment (i.e., a quick question during lecture to assess if students are understanding the concepts being discussed). PI Dempsey has also attended several Cutting Edge workshops, including a "Workshop on Student Learning: Observing and Assessing" and "Using Global Data Sets in Teaching Earth Processes".

Builds on resources available through the department, college, and university

The Geosciences Department and the University strongly support the project. The Department recognizes the need for the proposed Geosciences teaching and learning community, and for more graduate student support and mentoring (see letter of support from Dr. Garcia, Department Chair). The Department is committed to supporting the project by providing some released time during the semester for PIs to organize project activities and by providing some resources for continuing the project beyond the length of the grant period. For example, the Department will continue to hire undergraduates to serve as peer facilitators in introductory laboratory courses. The College of Science and Engineering (COSE) has committed funds for remodeling the classroom where we plan to create the new Geoscience Exploration Lab (GEL) and the Academic Technologies unit will install a new projection system with an EchoSystem to record classroom events (see letter from Dr. Garcia). Funds for laboratory supplies (for experiements such as the density lab described previously) are available from existing student laboratory fees. These fees, which yield about $5000 per year, will help us maintain the lab into the future. Other resources are the COSE's Center for Science and Mathematics Education (see Dr. Ozer's letter of support) and the University's Center for Teaching and Faculty Development (CTFD), which may provide released time and/or mini-grant funding for project-related activities. CTFD staff have extensive experience in Universal Learning Design (ULD) and will help us to make our materials accessible to everyone.

Achieves a broad impact, including many students from groups underrepresented in the Geosciences

As described above, the project will directly impact the >500 students who enroll each year in both the lecture and lab components of our introductory geoscience courses, and less directly an additional ~1400 students who enroll only in the lecture courses. In our GE courses at SF State, we have the opportunity to reach a large number of students who are from groups underrepresented in the geosciences and often economically disadvantaged. SF State is the fourth largest campus in the California State University (CSU) system, with an enrollment of >30,000 students, ~75% of which are undergraduates. SF State is widely recognized as one of the most ethnically and culturally diverse campuses in the United States; students of color make up ~60% of the undergraduate population. The CSU system is committed to providing educational opportunities to the broadest range of the state's citizens and provides the most affordable university education in California, frequently representing the only option for economically disadvantaged students. Our GE courses include many students who will go on for elementary and secondary teaching credentials (teacher training is a large component of the CSU's mission), and these students will particularly benefit from our project activities.

Research and teaching are integrally related at SF State, where it is a priority to engage students fully in the research process and to ensure that students from backgrounds underrepresented in the sciences receive high-quality research training. From 1990–today, extramural funding has grown from $12 million to >$50 million. The College of Science and Engineering (COSE), which is responsible for a majority of that funding, includes student involvement in research as part of its mission statement. The active research programs of Geosciences Department faculty provide us the opportunity to bring cutting-edge research into the classroom, even in introductory geoscience courses.

This project will provide partial support for a graduate student in the M.S. in Geosciences degree program. Although the student will be in the Geosciences Department, the thesis work will be supervised by Dr. Kimberly Tanner, Assistant Professor of Biology, whose research focuses on science education. The student's thesis project is part of our program assessment strategy (see Evaluation section below).

Project activities will directly benefit our GTAs and the undergraduate students participating as peer facilitators. Furthermore, the enhanced culture for teaching and learning is expected to infuse the Department and have at least indirect benefits to most of the ~100 students who are majors in our programs.

Evaluation—How We'll Measure our Success

We expect two groups of people to benefit most from our project: (1) students in our introductory (GE) geosciences courses; and (2) the instructors for those courses. We expect the members of our Teaching and Learning Community (TLC)—i.e., tenured/tenure-track faculty, lecturers, GTAs, and undergraduate peer facilitators—to experience one set of outcomes, namely, to learn more about science teaching and curriculum development, appreciate teaching more as a profession, and become better teachers. We expect these TLC participants, working collaboratively to develop lab materials and implementing them in the Geosciences Exploration Lab (GEL), to produce another set of outcomes for our GE students: to improve student understanding of (a) geosciences concepts and (b) the process of science, and to (c) acquire a more positive attitude about science in general and the geosciences in particular. In the longer run, we expect the larger community of introductory geosciences teachers and learners to benefit from the instructional materials and the instructional and professional development model that we create.

External Assistance. To help us assess and evaluate our progress, we will engage four people external to the Department of Geosciences. One is Anne Egger, a geosciences educator and Undergraduate Program Director for the Department of Geological and Environmental Sciences at Stanford University (see her letter of support). She serves as an editor for Visionlearning, a NSF-funded project with peer-reviewed materials for learning about the process of science. She is co-convening the July 2009 Cutting Edge workshop, "Teaching the Process of Science", that co-PI Dempsey plans to attend. She has experience both with explicit instruction about the process of science in her own introductory geoscience courses and with integrating GTAs into a teaching team that resembles our proposed TLC (Dunbar et al., 2008). Egger will help us measure (1) student understanding of the process of science and (2) the professional development of our GTAs and undergraduate peer facilitators.

Another major contributor will be Dr. Kimberly Tanner, Assistant Professor of Biology at SF State and Director of the Science Education Partnership and Assessment Laboratory (SEPAL) in our College of Science and Engineering (see her letter of support). Dr. Tanner, a former NSF Postdoctoral Fellow in Science Education, teaches Sci 750/850 (Science Teaching for Scientists I and II), a pair of graduate courses that introduce GTAs to issues in teaching and learning in the larger context of science education, which most GTAs in our TLC will take as part of their professional development. She has already successfully mentored two of our M.S. students with geoscience-education thesis topics, and she will serve as the major advisor for another Geosciences M.S. student who will be specifically recruited to conduct thesis research assessing and evaluating student learning and attitudes in our introductory geosciences labs, starting Fall 2010. Dr. Tanner will help us, along with Anne Egger, to evaluate the professional development of our TLC members.

Two other local science educators will be recruited to help advise and evaluate the project. In the rich scientific community of the San Francisco Bay Area, there are many potential candidates. Our specific choices will depend on the needs that seem most pressing at the time of project implementation. Together with Dr. Egger and Dr. Tanner, they will serve on our advisory board.

Summative evaluation of student learning and attitudes. To establish a baseline against which to measure our subsequent progress, in Spring 2010 we will administer a pre/post-semester assessment of students in our existing introductory geosciences lab classes, measuring student understanding of (a) geosciences concepts and (b) the process of science, and (c) student attitudes about science, to see how much these measures change over the course of the semester. These students will serve as our control group. For consistency we will employ the same assessment instruments to measure changes in student learning and attitude in the labs after innovations are implemented in Fall 2010.

To select appropriate pre/post-semester assessment instruments, we will consult Tanner and Egger, as well as the Science Education Resource Center's "Assessing Geoscience Concepts, Skills, and Attitudes" web site, which compiles a wealth of geosciences student-assessment instruments, literature, and advice. Candidate instruments include the multiple-choice Geosciences Concept Inventory (Libarkin and Anderson, 2005), which is currently undergoing revision but has been widely used for measuring concept knowledge in introductory geosciences courses; the BioQuest: Understanding Science program's Thinking about Science survey (http://undsci.berkeley.edu/teaching/ thinking_about_science.doc), a Likert-scale survey for measuring knowledge about how science works (based on a similar survey by Lombrozo et al., 2008); and the Test of Science-Related Attitudes (TOSRA; Fraser, 1981), another Likert-scale survey for measuring attitudes about science. These survey instruments have sometimes failed to detect changes in student knowledge, abilities, and attitudes that other assessments such as interviews and focus groups sometimes capture (Slater et al., 2008), so we will likely implement several diverse instruments to measure changes in student learning and attitude. These instruments will provide much of the data for a summative evaluation of student learning and attitude, which Dr. Tanner's M.S. student will prepare.

One bottom-line measure of student attitude of particular interest is the number of students who choose to take one or more additional courses in the geosciences even when they don't have to, and who even become one of our majors. We have enrollment data that enable us to measure this aspect of student behavior in the recent past and we will look for changes after we implement the project.

Formative assessment of student learning and attitudes. We will also need to assess the effectiveness of individual lab materials and how we use them pedagogically. Each lab assignment will have (a) its own, specific learning objectives and outcomes articulated to those of the course, and (b) a rubric to provide criteria for evaluating student performance. When GTAs score an assignment, the resulting feedback to the student also provides formative assessment data to us, which we can use to modify that activity and also others before they're assigned. To supplement these evaluations of student work, undergraduate peer facilitators and GTAs will record observations of students while they work (following protocols that we will train them to use), and Dr. Tanner's M.S. student might gather additional data (e.g., via interviews of individual students). TLC participants will meet weekly in a one-unit semester course ("Our Dynamic Classroom"), designed to offer the lead instructors, GTAs, and undergraduate peer facilitators pedagogical support specific to the introductory labs. Participants will report and examine their assessment data and make adjustments to lab activities and instructional strategies, as appropriate.

Formative assessment of professional development in teaching. Professional development of some members of our Teaching and Learning Community (TLC) will begin with a one-day curriculum-development workshop in summer 2010, conducted by Cathy Manduca of Carleton College's Science Education Research Center (SERC) and Anne Egger. They are veteran Cutting-Edge workshop facilitators and we expect them to provide guidance about how best to assess the impact of their workshop (see their letters of support).

Thereafter, we will consult with Anne Egger and Kimberly Tanner, together with "Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics" (NRC, 2003), for guidance about how best to assess the development of our GTAs and undergraduate peer facilitators. Many of the GTAs will enroll in Dr. Tanner's Sci 750/850 courses and she will evaluate them in that context. All TLC participants in "Our Dynamic Classroom" seminar course will discuss issues about teaching and learning in the introductory labs. As one example of a likely teaching assessment, the Geosciences Exploration Lab (GEL) facility will be equipped with video-recording capability, so we can record class sessions, analyze recordings, and provide feedback to session instructors.

Summative evaluation of professional development in teaching. Standard, departmental, end-of-semester teaching evaluations by students will provide one source of data about the teaching effectiveness of instructors. We expect to supplement these student surveys to address aspects of teaching performance specific to the pedagogical strategies that we use in the labs. Again, we will seek the advice of our outside collaborators. Our lecturers, GTAs, and undergraduate peer facilitators will provide feedback about their view of our professional development efforts (notably Sci 750/850 and "Our Dynamic Classroom" course) through written surveys and interviews, which the advisory board will conduct for us (see Anne Egger's letter of support).

Impact on the larger community. We will be able to measure this impact by the numbers of geoscience educators who purchase our laboratory materials and by initial responses to the materials and methods we place on the SERC and other web sites. We can measure early levels of interest by the number of "hits" these materials attract, and we can learn about others' responses to our materials and methods through interactions with colleagues at conference and workshop presentations and via other communications. Some measures of this larger impact won't come until after the grant period has ended.

How We'll Disseminate Our Results

We will disseminate our results through a large variety of means (see Project Timeline for the timing we envision). After initial implementation, we will present project results at the American Geophysical Union and Geological Society of America national conferences (and possibly others) to share experiences and get feedback. Once the laboratory activities have been used and tested, we will bundle them into manuals (one for each discipline) and market them to other Geoscience departments. Because we will focus on problems relevant to the local region, we imagine the manuals will be most useful to community colleges and university departments in the San Francisco Bay Area, but we expect the materials to be relevant and adaptable throughout California and even beyond. Some of the activities will be submitted to teaching and learning web sites such as the Science Education Resource Center (SERC; see letter from C. Manduca). We will also create modules about the Teaching and Learning Community (TLC) that we have created and the ways that we have implemented the process of science into our materials that will also be submitted to resources web sites such as SERC and disseminated via conference presentations and workshops at SF State and possibly elsewhere. In the last year of the grant period, we will work together with Kimberly Tanner, the M.S. student she is advising, and our other collaborators to write at least two manuscripts that will be submitted to journals like the Journal of Geoscience Education for publication.

Results from Prior NSF Support

NSF-GEO 0119828, $1,250,169, 2001-08, SF-ROCKS (Reaching Out to Communities and Kids with Science in San Francisco), PI/Director: L. White, Co-PIs: K. Grove and D. Dempsey.

Results: (1) The summer research institute, a centerpiece of the SF-ROCKS program during the summers of 2003-2007, resulted in 60 high-school students from groups underrepresented in the geosciences participating in investigations of Earth and environmental science problems. Since December 2003, SF-ROCKS student research teams have presented their work at AGU in poster sessions for high-school student research. (2) Dissemination of place-based research highlighting SF-ROCKS projects has generated more than 30 publications, 25 of which have high school or college student co-authors. The research largely details studies in the S.F. Bay Area and often in the neighborhoods where the students live. (3) Since 2001, academic development of college students has been an important goal and ten graduate students, twenty undergraduate students, and six community college students have been supported and trained as research group leaders or project assistants. (4) SF-ROCKS has developed lesson plans that are used in a variety of ways by teachers of 9th-grade integrated and earth science at our partnership high schools. The lesson plans have been widely disseminated via our website (http://sf-rocks.sfsu.edu/lessons.htm). Since 2001, more than 800 9th-grade students in Integrated Science courses at 5 local high schools have been exposed to our lesson plans in some form.

NSF- OCE 0823688, $230,808, 2008-2011, RUI:Tropical–subtropical linkages during the Pliocene-Pleistocene, PI: P.S. Dekens

This project, which will reconstruct sea surface temperatures and vertical water column structure at a site in the south Atlantic (ODP site 1264) through the last 5 million years, has recently been funded. Samples have been acquired, and lab preparations have begun. Dominika Wojcieszek, a graduate student in the Department of Geosciences at SF State has begun work on this project. I expect she will collect a significant portion of the data over the summer and present initial results at the 2009 Fall AGU meeting.

Project Timeline

When?	Who?	What?
Spring 2010	GTAs	3 recruited to participate in curriculum development
	PIs	Purchase equipment for GEL; Organize professional development workshop; complete pre-project assessment in Our Dynamic Earth/Ocean/Atmosphere (E/O/A); organize TLC
Summer 2010	GTAs	Curriculum development
	PIs	Curriculum development
	All TLC members	Attend professional development workshop
Fall 2010 (1st implimentation)	PIs	Teach "Our Dynamic Classroom" seminar class and lecture portion of Our Dynamic E/O/A classes; work on assessment plan
	GTAs (grant funded)	Curriculum development and revision; teach lab section
	GTAs (not grant funded)	Teach lab section
	UGPFs (grant funded)	Facilitate lab activities (peer facilitators)
	All TLC members	Attend "Our Dynamic Classroom" seminar class
	MS student	Begin work on thesis proposal with Dr. Tanner
	Advisory Board	First visit: attend lecture/lab sections of E/O/A courses, "Our Dynamic Classroom"; meet with TLC; interview GTAs/UGPFs
Spring 2011 (2nd implimentation)	PIs	Teach "Our Dynamic Classroom" and lecture portion of Our Dynamic Earth/Ocean/Atmosphere; continue assessment plan
	GTAs (grant funded)	Curriculum development and revision
		Teach lab section
	GTAs (not grant funded)	Teach lab section
	UGPFs (grant funded)	Facilitate lab activities (peer facilitators)
	All TLC members	Attend "Our Dynamic Classroom" seminar class
	MS student	Teach lab section; finalize thesis proposal and begin program assessment
Summer 2011	PIs	Refine laboratory activities; refine "Our Dynamic Classroom"; contact potential publishers; submit abstracts to relevant meetings
	MS Student	Analyze data so far, revise assessment strategy, work on thesis
Fall 2011 (3rd implimentation)	PIs	Teach "Our Dynamic Classroom" and lecture portion of Our Dynamic E/O/A; present at Fall AGU and GSA national conferences
	GTAs (grant funded)	Curriculum development and revision; teach lab section
	GTAs (not grant funded)	Teach lab section
	UGPFs (grant funded)	Facilitate lab activities (peer facilitators)
	All TLC members	Attend "Our Dynamic Classroom" seminar
	MS student	Continue program assessment
	Advisory Board	2nd visit: attend lecture/lab sections of E/O/A courses, "Our Dynamic Classroom" seminar; and meet with TLC; interview GTAs/UGPFs
Spring 2012	PIs	Write manuscript drafts; lab manual published; post modules about activities on SERC and other web sites; continue assessment plan
	GTAs (not grant funded)	Teach lab section
	UGPFs (dept funded)	Facilitate lab activities (peer facilitators)
	All TLC members	Attend "Our Dynamic Classroom" seminar
	MS student	Finish thesis
Summer 2012	PIs	Submit manuscripts for publication; complete publication of material on SERC and other web sites

REFERENCES CITED

Anderson, S. and Libarkin, J., 2008, Mobility of college-level student ideas as revealed by the geoscience concept inventory: implications for teaching introductory courses: EOS Transactions AGU, v. 89, n. 53, Fall Meeting Supplement, Abstract ED41B-01.

Bralower, T.J., Feiss, P.G., and Manduca, C.A., 2008, Preparing a new generation of citizens and scientists to face Earth's future: Liberal Education, p. 20–23.

Bransford, J., Pellegrino, J.W., and Donovan, D., 1999, How people learn: bridging research and practice: National Academy Press, Washington, D.C., 74 pp.

Champagne, A.B., Klopfer, L.E., and Gunstone, R.F., 1982, Cognitive research and the design of science instruction: Educational Pschologist, v. 17, p, 31–53.

Dempsey, D., 2001, Action Research in Planetary Climate Change, a Geosciences Course for Preservice Secondary Science Teachers: Presentation at the NASA-NOVA Leadership Development Conference, Washington, D.C. (http://funnel.sfsu.edu/courses/gm310/assessment)

Dempsey, D., 2002, An Example of a NOVA Course: GEOL/METR 310, Planetary Climate Change: Presentation at the NASA-NOVA Program Workshop, NASA-Ames, Mountain View, CA.

Dempsey, D., 2003, Global Weather Animations: JavaScript Tools and a Pedagogical Application: Presentation at the NASA-NOVA Leadership Development Conference, Houston, TX.

Dempsey, D. and Quita, I., 2004, Problem-Based Learning in an Integrated Geosciences Course for Future K-8 Teachers (poster): Invention and Impact: Building Excellence in Undergraduate Science, Technology, Engineering and Mathematics (STEM) Education: American Association for the Advancement of Science, Washington, D.C., p. 317.

Dempsey, D., O'Sullivan, K., Grove, K., White, L., Schultz, G., and Dutton, D., 2000, Impact of National Science Education Standards (NSES) on Curriculum: Planetary Climate Change, a Geosciences Course for Pre-service Secondary Science Teachers (and Others): EOS Transactions AGU, v. 81, n. 48, Fall Meeting Supplement, Abstract PA61A-09. (http://funnel.sfsu.edu/courses/gm310/F00/development/AGU/index.htm)

Dunbar, R.W., Egger, A.E., and Schwartz, J.K., 2008, Evolving roles for teaching assistants in introductory courses: EOS Transactions AGU, v. 89, n. 53, Fall Meeting Supplement, Abstract ED41B-07.

Egger, A., cited 2009, What is teaching the process of science?: SERC/Visionlearning web site about Process of Science: http://serc.carleton.edu/sp/process_of_science/what_process_science.html

Etkina, E., and Mestre, J.P., 2004, Implications of learning research for teaching science to nonscience majors: A Sencer backgrounder for discussion at SSI-2004 (report on research supported by NSF-CCLI grant DUE-0088753), 26 pp. (http://www.sencer.net/Resources/pdfs/Backgrounders/ImplicationsofLearningResearchforTeachingScience.pdf)

Fox, M.A., and Hackerman, N., eds., 2003, Evaluating and improving undergraduate teaching in science, technology, engineering, and mathematics: The National Academies Press, Center for Education, National Research Council, Washington, D.C., 215 pp.

Fraser, B.T., 1981, TOSRA: Test of Science Related Attitudes Handbook: Australian Council for Educational Research, Hawthorne, Victoria, Australia.

Grove, K., 1998, On-line materials to foster active learning in a large-sized ocean science course: EOS Transactions AGU, v. 79, n. 45, p. F514.

Grove, K., 2001, "Virtual Voyages": introducing science with real-world data in a large classroom: Geological Society of America Abstracts with Programs, v. 33, n. 6, p. A-350.

Grove, K., 2002, Using online homework assignments to implement the learning cycle in large courses for general education: Journal of Geoscience Education, v. 50, n. 5, p. 566-574.

Johnson, D.W., Johnson, R.T., and Smith, K.A., 1998, Cooperative learning returns to college: Change, v. 30, p. 26–35.

King, A., 1993, From sage of the stage to guide by the side: College Teaching, v. 41, p. 30–36.

Libarkin, J.C., and Anderson, S.W., 2005, Assessment of learning in entry-level geoscience courses: results from the Geoscience Concept Inventory: Journal of Geoscience Education, v. 53, p. 394–401.

Lombrozo, T., Thanukos, A., and Weisberg, M., 2008, The importance of understanding the nature of science for accepting evolution: Evolution: Education and Outreach, v.1, n. 3, p. 290–298.

Manduca, C.A., Baer, E., Hancock, G., Macdonald, R.H., Patterson, S., Savina, M., and Wenner, J., 2008, Making Undergraduate Geoscience Quantitative: EOS Transaction AGU, v. 89, n. 16, p. 149-150. (http://serc.carleton.edu/serc/EOS-89-16-2008.html)

McConnell, D.A., Steer, D.N., Owens, K.D., and Knight, C.C., 2005, How students think: implications for learning in introductory geoscience courses: Journal of Geoscience Education, v. 53, p. 462–470.

Mintzes, J.J., Wandersee, J.H., and Novak, J.D., eds., 1997, Teaching science for understanding: A Human Constructivist View: Academic Press, 360 pp.

Novak, G.M., Patterson, E.T., Gavrin, A.D., and Christian, W., 1999, Just-in-time Teaching: Blending active learning with web technology: Prentice Hall, 188 pp.

Oliver-Hoyo, M., and Beichner, R., 2004, SCALE-UP; Bringing inquiry-guided learning to large enrollment courses: *in* Lee, V.S., ed., Teaching and learning through inquiry: Stylus Sterling Publishing, Virginia, p. 51-62.

Petcovic, H.L., and Ruhf, R.J., 2008, Geoscience conceptual knowledge of preservice elementary teachers: results from the Geoscience Concept Inventory: Journal of Geoscience Education, v. 56, p. 251–260.

Slater, T.F., Slater, S.J., Lyons, D.J., Manhart, K., Wehunt, M., Kapp, J., and Richardson, R.M., 2008, Measuring the impact of active learning in a redesigned large-enrollment introductory geoscience survey course: EOS Transactions AGU, v. 89, n. 53, Fall Meeting Supplement, Abstract ED41B-03.