KECK WORKSHOP ON TEACHING GEOPHYSICS

ORGANIZERS

Randy Richardson, University of Arizona
Rob Sternberg, Franklin & Marshall College

PARTICIPANTS

Susan Beck, University of Arizona
Peter D. Crowley, Amherst College
Eric B. Grosfils, Pomona College
Michelle Hall-Wallace, University of Arizona
Tekla Harms, Amherst College
M. Frank Watt Ireton, American Geophysical Union
Roy Johnson, University of Arizona
Glenn Kroeger, Trinity University
Bob Lillie, Oregon State University
Cathy Manduca, Keck Coordinator
Steve Myers, University of Arizona
Kevin Pogue, Whitman College
Edgar W. Spencer, Washington & Lee University
Dick Stenstrom, Beloit College
Ben Sternberg, University of Arizona
Mark Tinker, University of Arizona
Terry Wallace, University of Arizona
George Zandt, University of Arizona

OTHER ACTIVITIES

One of the consortium's achievements has been to create a community of students, faculty and alumni from the 12 college geology departments. We were very pleased to have more than 70 members of this community together at the Keck Consortium breakfast at the fall meeting of the Geological Society of America in Denver. We continue to communicate with alumni using both mail and e-mail and will soon publish the second Keck Alumni Newsletter. Our web site (www.carleton.edu/curricular/GEOL/resource/keck/keck.html) has expanded this year and now contains information for applicants, alumni and faculty and student participants in our programs.

The Keck Consortium is working with the American Geophysical Union to produce a report entitled "Shaping the Future of Undergraduate Earth and Planetary Science Education–Innovation and Change using an Earth System Approach." Funded by the National Science Foundation, the report is designed to provide a framework for changes in earth and planetary science education over the next decade. Nine consortium faculty joined with 37 educators from colleges and universities across the country to meet for a three-day workshop in November. There they discussed how earth scientists can best respond to the need for educating a scientifically literate population while training the next generation of geoscientists. Workshop participants formed panels to address key topics including how and why to teach earth system science, the integration of research and education, diversity issues, connections with K-12 and lifelong education, and the need to change the academic culture to pursue these goals. The consortium was represented on each panel by at least one faculty member ensuring a strong voice for liberal arts colleges in the discussion. Lori Bettison-Varga from the College of Wooster is serving as the chair of the panel addressing the integration of research and education. The report will be released in the spring of 1997 and will be presented at the Spring Meeting of the American Geophysical Union in Baltimore.

We continue to collaborate with Project Kaleidoscope on workshops for the entire geoscience education community. Several Consortium faculty are serving on the Earth and Planetary Science workshop series advisory board which is co-chaired by Cathy Manduca, consortium coordinator. The second workshop in the series, "Reforming Earth and Planetary Science Curricula: What Works?", will be held at Whitman College next October.

The activities of the consortium are directed by a board containing one representative from each school and the consortium coordinator. The representatives met twice during the year: at the April 1996 symposium at Williams College and at the October, 1996 Geological Society of America meeting in Denver. Business included project and workshop selection for the upcoming year, student selection procedures, NSF and Keck Foundation proposals, program evaluation, and sexual harassment and alcohol policies. The board committed to a fund raising campaign to ensure long term funding for the program and expanded the consortium coordinator position to accomplish this goal.

ACKNOWLEDGEMENTS

The continued commitment of the W.M. Keck Foundation to the consortium for the past ten years has allowed the program to grow and thrive. It has been a particular privilege to work with Program Vice-President Dr. Sandra Glass and to benefit from her insights into science education and research. She has been an inspiration to all people associated with the consortium since its inception. We will miss her as she moves on from her position at the Foundation and wish her well in her life ahead. The National Science Foundation has also provided substantial support for our program. Their program officer, Dr. Mike Mayhew, has been exceptionally helpful in providing guidance for the continued growth of our program. Finally, we have been supported by our own institutions: by their financial contributions directly to our program, by department and institutional funds used to augment student research and travel to professional meetings, and by their intellectual support of our activities.

The administration of the program has benefited from the cooperation of the Carleton College business office, particularly Beverlee DeCoux, Comptroller, Barb Fowler, Accounting Assistant, and Shirley Dulski, Accounts Payable Specialist. The coordinator has been aptly aided by Elizabeth Rider and Peter Goss, Administrative Assistants. This year the symposium was organized by Mark Wilson and Amy White at The College of Wooster, and the symposium proceedings were edited by Carol Mankiewicz and Carl Mendelson at Beloit College. We appreciate their hard work and the excellent job that they have done. The most pleasurable aspect of coordinating the consortium is working with the consortium faculty, particularly the representatives and project directors. Thank you very much for your dedication to the consortium, your enthusiasm about each of new idea, and your help in making things run smoothly.

Keck Workshop on Teaching Geophysics

Rob Sternberg, Workshop Co-organizer
Department of Geosciences, Franklin & Marshall College, Lancaster, PA 17604-3003

Randy Richardson, Workshop Co-organizer
Department of Geosciences, University of Arizona, Tucson, AZ 85721

OVERVIEW

The Keck Workshop on Teaching Geophysics was held at the University of Arizona, Tucson, March 14-17, 1996. The Workshop was co-sponsored by the Keck Geology Consortium and the College of Science, University of Arizona. The focus of this Keck Workshop was on the teaching of geophysics, primarily at the undergraduate level. A sub-theme was the teaching of geophysics, "big and small"; that is, what does the teaching of geophysics at a liberal arts college and a research university have in common, and how does it differ. Holding the workshop at Arizona provided the opportunity for presentations by Arizona faculty on their research along with visits to state-of-the-art laboratories.

Some of the "conclusions" drawn at the Workshop could be summarized as follows:

1) How we teach geophysics clearly depends on our intended audience, whether it be graduate students in geophysics, quantitatively oriented undergraduates, or the typical geology undergraduate.
2) At the undergraduate level, geophysics should be integrated into the curriculum with other geoscience courses; conversely, quantitative thinking should be distributed across the geosciences curriculum.
3) A variety of modern pedagogical methods are being used increasingly in geophysics.
4) Preparation in cognate sciences, mathematics, and creative thinking are critical for graduate work in geophysics.
5) Field work and computing remain as important components of geophysics education.
6) Increased cooperation between graduate departments at research universities and undergraduate departments at smaller colleges, and between academia and industry, should have benefits for everyone involved.
7) It behooves us to keep in mind that most students would eventually like to have jobs in their chosen fields.
8) An ftp site will be set up at Trinity University to contain relevant documents, eventually reachable via a www page. A session will be offered at the 1997 national GSA meeting in Salt Lake City. Further collaboration between Keck and the University of Arizona is anticipated.

WHOM SHOULD WE TEACH? WHAT SHOULD WE TEACH THEM?

Thursday evening's session started with introductions and brief descriptions of geophysics programs at the various schools. Most of the Keck schools have a single course in geophysics, taught by people with variable amounts of geophysical training themselves. These courses also represent various mixes of "solid earth" and "applied" geophysics. In contrast, the Arizona program consists of nine geophysics courses that undergraduates can take, taught by six geophysics professors. The theme for this evening was *Geophysics for undergraduates: small (liberal arts college experience) and large (university experience).* Rob Sternberg and Randy Richardson started the discussions with opening comments.

Two of the persistent questions of the Workshop emerged early—whom should we teach, and what should we teach them? For example, the geophysics course at Trinity is taught every other year as an elective, to a mix of geology, physics and engineering majors, and is mathematically rigorous. In contrast, the main geophysics course at Franklin & Marshall is taught every year to almost only geosciences majors, is required for the geosciences major, and uses much math but mostly pre-calculus. The Trinity course has reached fewer students overall, but has resulted in proportionally more graduate students in geophysics, including Mark Tinker, now at the University of Arizona, and a participant in this Workshop.

At Arizona, a student can obtain an undergraduate major in geophysics, requiring a year of calculus, differential equations, linear analysis, three semesters of physics and a year of chemistry. The first geophysics course is currently taken as a junior, with a prerequisite of two semesters of physics. This geophysics course is also required for the geosciences major. The geosciences program at Arizona is being revised. Four core courses will be required for all geoscience majors, including a course on structural geology and geophysics, to be taught every semester.

Geophysics will thus be introduced at an earlier point in the curriculum, requiring one semester of calculus. Oregon State is also going to a two-quarter sequence of geophysics and tectonics.

WRITING; FACILITIES; QUANTITATIVE ISSUES

The Friday morning session started with a discussion of *What can be gained from a workshop such as this?* Frank Ireton, AGU, posed the question "What are the employment opportunities over the next few years?" He suggested we consider a Chapman Conference on the teaching of geophysics, although this idea was not enthusiastically embraced by the participants. AGU could help with other goals, such as K-12 education projects. Terry Wallace argued that policy is what drives government decisions, regardless of science. Jobs for scientists is not a priority on the national agenda. This presaged ongoing questions about what we should prepare our students for. Do we want students to love their research, while fully understanding their careers may lie elsewhere? Do we want to help prepare students for alternative careers in science? Do we want to tailor the number and specialties of our students to attempt to match the anticipated job market?

Gene Levy, Dean of the College of Science at the University of Arizona, welcomed us on behalf of the College. Cathy Manduca reviewed the history of the Keck Consortium.

Bob Lillie discussed his use of structured writing in a two-semester geophysics sequence. Rather than covering geophysics by technique, these courses focus on three boundaries—topography, crust-mantle, and lithosphere-asthenosphere. Papers are written on a particular geologic area, which gives a context for the various geophysical methods. Tekla Harms, Sue Beck, Glenn Kroeger, Kevin Pogue and Randy Richardson also commented favorably on writing after engaging with the primary literature. Even in introductory courses, students can delve into the literature at an appropriate level, such as *Scientific American*. Students also benefit from learning about the hierarchy of the scientific literature, and the concept of peer review. Bob summarized the payoffs of his approach to teaching: regional emphasis; writing is taught as a process; information is incorporated incrementally; papers improve as they expand; grading is also incremental; writing ethics (e.g., plagiarism) are learned.

Friday afternoon was reserved for lab and facilities tours. We were able to see the paleomagnetism lab, thanks to Dave Richards, a post-doc in Bob Butler's lab. Roy Johnson showed his reflection seismology laboratory; this generated enthusiasm for incorporating more reflection seismology in our geophysics classrooms or a future Keck project. Michelle-Hall Wallace gave us a tour of some worldwide web seismology resources in CLUE, the Computer Laboratory for Undergraduate Education. Terry Wallace, Mark Tinker and Steve Myers demonstrated some other seismic resources in Terry's lab, and showed a new low-cost, three-axis broadband seismometer. Across campus at the College of Mining and Geological Engineering, Ben Sternberg showed us some of LASI's (Laboratory for Advanced Subsurface Imaging) field geophysics equipment.

Friday evening focused on quantitative issues. Terry Wallace commented that the most important issue is to teach our students how to think using mathematics (through differential equations). Glenn Kroeger feels that math should be taught across the curriculum in order not to hold the geophysics course back, but that geophysics is the best place to teach some complex math in a specific context that will make sense to the student. Glenn also mentioned that he hands out pre-typed proofs to students, who can then spend their energy understanding rather that copying. Mark Tinker, one of Glenn's former students, added that there could be separate expectations for comprehending a mathematical argument, and being able to execute one. In terms of computer skills, Terry felt that C++ is perhaps the best programming language, FORTRAN is a still-useful dinosaur, *Mathematica* and *Matlab* (the latter also endorsed by Glenn Kroeger) might suffice. Spreadsheets are often good enough for classwork but not adequate for graduate research. How much physics is a more difficult question. Writing is another important skill.

EXERCISES; EQUIPMENT; FIELD WORK

Saturday morning included a warm welcome from Joaquin Ruiz, head of the Department of Geosciences at the University of Arizona, who encouraged us to find ways to facilitate future cooperation in teaching and learning between the Keck schools and the University of Arizona. Our discussion started with a sharing of some favorite classroom ideas, followed by some discussion of problem sets and computer exercises. These included overnight field trips, back-of-the-envelope problems, specific applications of mathematics to geophysical problems (e.g., plate momentum; isostasy; derivation of wave equation; Snell's law from ray parameter p; Snell's law from Fermat's principle); case histories (thought by Ben Sternberg to be quite useful for employment in industry). Rob Sternberg's favorite classroom demonstration uses bar magnets and a fluxgate magnetometer to illustrate marine magnetic anomalies. Roy Johnson showed how connected slinkies can generate wave reflection and mode conversion. Terry Wallace demonstrated that connected people (hand-to-shoulder) can transmit P-waves, but the velocity depends on the rigidity with which they are connected. Randy Richardson had us transmit a "wave" across the room, as happens at sporting events.

Saturday morning closed with some discussion of employment opportunities. Ben Sternberg spoke in part from his background in industry. He sees an issue of balancing the output of geophysicists against the need. Mining

geophysics now has increasing opportunities, albeit mostly abroad. Nonetheless, he would like to see more American students continue on to graduate school in this field.

Much of the afternoon concentrated on equipment and field work. Most of the workshop avoided the distinction between "solid earth" and "applied" geophysics, but when we talked about field work or field geophysics we were usually referring to what is often called applied geophysics. Amherst College recently was awarded an NSF ILI (Instrumentation and Laboratory Improvement) grant to acquire a seismograph, a magnetometer, survey equipment, and to repair a gravimeter. The proposal focused on a multi-year study of the Deerfield Basin. A weakness in the proposal was the dissemination of the teaching results. Obtaining the equipment will enable a lab component to be added to the course that at first had no lab at all, and later had lab sessions that were oriented towards problem-solving. Michelle Hall-Wallace has sat on the review panel for the ILI program. She stressed that only innovative proposals with a clear idea will stand out from the pack. A grab-bag approach is not the best, nor are requests to replace obsolete equipment. Roy Johnson pointed out that construction companies sometimes have useful surplus equipment that could be donated to a college. Ed Spencer gave a detailed account of his field-oriented geophysics course at Washington & Lee. After students are introduced to the instruments, they are sent out to make measurements on their own.

The afternoon concluded with some comments from graduate students Mark Tinker and Steve Myers. Steve listed four items useful for working in the environmental field, where he also has prior experience: 1) recognition of the pros, cons and costs of various geophysical methods; 2) the ability to apply math to problems; 3) one should understand the methods one uses, rather than play with "black boxes"; 4) geophysical interpretations must be geologically reasonable. The majority of our students get masters' degrees; several participants thought that a master's degree would be a good degree even for those students eventually obtaining Ph.D.'s, and should not be viewed as a consolation degrees in the more high-powered departments.

Saturday evening consisted of an excursion to Gates Pass, Tucson's favorite sunset hangout, and a delightful Mexican dinner.

WHERE DO WE GO FROM HERE?

The workshop concluded on Sunday morning as we tried to answer the question of *Outcomes: Where do we go from here?* We agreed that Rob Sternberg would write up a summary for the Keck Consortium, and Randy Richardson would do the same for *EOS*, and possibly *GSA Today*. Glenn Kroeger has set up an ftp site at Trinity—the host is "omniscience.mms.trinity.edu", the account name is "geophys", and the password was agreed upon at the Workshop. There is a skeletal set of subdirectories. Glenn recommends that we not open this to the public since there will be exams and problem sets, along with answers included. Once we have the material in hand, we can generate a web page that will point to the material that should be generally available. We also plan to offer a session at the 1997 national GSA meeting in Salt Lake City, co-organized by Kevin Pogue and Bob Lillie. Further plans for collaboration between the Keck Consortium and the University of Arizona could include a seismology project involving Glenn and Roy Johnson. Some specific leads were also provided to Cathy Manduca for contacts with industry.

On this last morning, Peter Crowley commented he was comforted by the fact that we all teach similarly, to which Ed Spencer replied "Not!" (well, ok, that's not an exact quote). Tekla Harms re-stated the importance of quantitative thinking across the geosciences curriculum, rather than having a single course in geophysics responsible for this task. Neither should geophysics only be mentioned in geophysics courses, but should be brought into other geology courses as well. For graduate work in geophysics, Kevin listed again for us the priorities of the important skills—mathematics, physics and creative thinking.

We left sunny Tucson with regrets, for it was still almost winter where many of us lived, and because our stimulating interactions concerning the teaching of geophysics would have to continue at a distance. However, the workshop gave us much to think about, and to act on in the future.

PARTICIPANTS

Attendees from the Keck schools were: Peter D. Crowley, Amherst College; Eric B. Grosfils, Pomona College; Tekla Harms, Amherst College; Glenn Kroeger, Trinity University; Kevin Pogue, Whitman College; Cathy Manduca, Keck Coordinator; Edgar W. Spencer, Washington & Lee University; Dick Stenstrom, Beloit College; Rob Sternberg (co-organizer), Franklin & Marshall College.

Attendees from the University of Arizona were: Susan Beck, Department of Geosciences; Michelle Hall-Wallace, Department of Geosciences; Roy Johnson, Department of Geosciences; Steve Myers, Department of Geosciences (Ph.D. student); Randy Richardson (co-organizer), Department of Geosciences; Ben Sternberg, Department of Mining and Geological Engineering; Mark Tinker, Department of Geosciences (Trinity alumnus, Ph.D. student); Terry Wallace, Department of Geosciences; George Zandt, Department of Geosciences.

Other attendees were: M. Frank Watt Ireton, American Geophysical Union; Bob Lillie, Oregon State University.

Earth Systems Science

Workshop

Faculty

Robert Carson, Whitman College
Andrew deWet, Franklin and Marshall College
Eric Grosfils, Pomona College
Richard W. Hazlett, Pomona College
Cathryn Manduca, Carleton College
Carol Mankiewicz, Beloit College
Stanley Mertzman, Franklin and Marshall College
Linda Reinen, Pomona College
Edgar Spencer, Washington and Lee University
John Winter, Whitman College
Donald Zenger, Pomona College

Visitors

Debra Colodner, Biosphere II Project, Columbia University
William Reeburgh, University of California at Irvine
Susan Trumbore, University of California at Irvine