
On the Cutting Edge: Improving Learning by Enhancing Teaching in the Geosciences

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The primary goal of the NSF-funded program *On the Cutting Edge* is to develop and offer a set of integrated, web-supported professional development opportunities for current and future faculty in the geosciences at various stages in their careers and to disseminate them widely, with the ultimate aim of improving the quality of geoscience teaching and student learning. Each year, we offer an integrated series of six multi-day workshops and one or more sessions or one-day workshops at professional meetings. The website for *On the Cutting Edge* (<http://serc.carleton.edu/NAGTWorkshops/index.html>) not only provides support for individual workshops, but also contains a growing collection of varied and valuable resources for teaching undergraduate geoscience. The website provides an effective means for reaching a wide audience beyond actual workshop participants. Evaluation of workshops to date demonstrates that *On the Cutting Edge* is effectively changing participants' teaching in the geosciences. In this chapter, we detail the rationale for the program and describe the program, the principles for workshop design, the use of the website, and the initial program evaluation. The program is sponsored by the National Association of Geoscience Teachers (NAGT), and we are part of the Digital Library for Earth System Education (DLESE) and contribute to the National Science Digital Library. The program is funded through five-year CCLI ND grants awarded by NSF DUE to each of the authors (DUE 0127310, DUE 0127141, DUE 0127257, and DUE 0127018).

Program Rationale

Undergraduate science education plays a pivotal role in the development of a scientifically literate public and the main-

tenance of the scientific workforce. An introductory science class is the most advanced science course taken by many students; K-12 teachers develop their understanding of science in these classes, and an undergraduate degree in science is a critical piece of the professional training for the scientific workforce. Improving STEM education at the undergraduate level emerged as one of the mandates of the 1990s and remains an important challenge in the 21st century. Project Kaleidoscope (PKAL), the National Research Council, NSF, and the American Geophysical Union all published documents calling for changes in science pedagogy at the undergraduate level (Project Kaleidoscope, 1991; National Science Foundation, 1996; National Research Council, 1996, 1999, 2000; Ireton et al., 1997).

Recognizing that many college and university faculty receive little formal training in teaching and remain largely unaware of advances in research on teaching and learning, one of the established methods for improving undergraduate science education is to enhance and support the ability of science faculty to teach effectively. NSF has a long tradition of workshops aimed at this goal (for example, the current CCLI program and previous Undergraduate Faculty Enhancement [UFE] program). Between 1994 and 2000, a collection of practical workshops for geoscience faculty sponsored and funded by various organizations (NAGT, PKAL, Keck Geology Consortium, and NSF) provided venues for dissemination of effective practice in teaching, course design, and career planning, as well as approaches for teaching particular topics.

The professional development program *On the Cutting Edge*, developed specifically for geoscience faculty, builds on this strong foundation, taking workshops to a new level by providing an integrated, synergistic workshop series and by

using the web for both workshop support and dissemination of workshop ideas and resources. The first objective of the program is to enhance teaching in the geosciences by involving a large number of undergraduate geoscience faculty and graduate students in a variety of linked workshops aimed at improving their content knowledge in emerging fields and their abilities to use effective teaching practices. The second objective is to broaden the reach of the program by developing effective online resources for disseminating workshop content. The third objective is to develop an active professional cohort of educators who will become involved in dissemination of content in emerging fields and exemplary practices in instruction, course design, and delivery of instructional materials for diverse audiences. The continuity provided by long-term funding has had a major impact on our ability to advertise, experiment with, and evaluate this project.

***On the Cutting Edge* Professional Development Program: An Integrated Workshop Series and Web Resource Especially for Geoscientists**

On the Cutting Edge builds on a strong model for workshops established over the last few decades (National Science Foundation, 1991) by adding three elements: a focus specifically on geoscience faculty; development of an integrated, synergistic workshop series; and capitalization of the power of the web. The geosciences are often overlooked in studies or workshops addressing science education (broadly defined), possibly because of the relatively small size of the discipline and its absence from most high school curricula in the United States and from required cognate courses in undergraduate science. However, the geosciences play a significant role in entry-level undergraduate courses (publishers estimate the introductory geoscience market at 250,000 students per year) and are critical to the development of a workforce that can address our growing environmental needs. The professional development program *On the Cutting Edge* focuses specifically on this important group of faculty.

The program offers a series of workshops that aim to move innovative and effective teaching methods and new understanding of geoscience into the main stream of geoscience education. In addition, the program seeks to support faculty at the various stages of their careers. To this end, *On the*

Cutting Edge offers four types of workshops. *Emerging topic workshops* are designed to move important new topics from an initial stage of early activity by isolated leaders in the field toward widespread implementation in undergraduate geoscience courses. *Mature topic workshops* provide an opportunity for a larger group to work on issues that will enable a wide dissemination into the mainstream of undergraduate geoscience practice. In addition to these workshops, which address different topics each year, three *annual workshops* are offered every year: course design in the geosciences, a workshop for early career geoscience faculty, and a workshop for graduate students and postdoctoral fellows on preparing for an academic career in the geosciences. The annual workshops provide a mechanism for bringing ideas to faculty at critical points in their career. In addition to these multi-day workshops, one-day *workshops at professional society meetings* provide an opportunity to work with faculty in shorter time intervals with minimal additional travel obligations. These workshops are particularly suited for expanding the audience for a topic. By moving ideas and leaders that emerge in one workshop into the programs for others, we have been able to increase the visibility and implementation of important ideas (for example, the role of research on spatial cognition in designing effective geoscience teaching materials, which was initially addressed in an emerging topic workshop, was the focus of a keynote address by a cognitive scientist at the opening of a mature topical workshop).

On the Cutting Edge also takes advantage of the new opportunities offered by the web both to enhance the workshop series for participants and to bring workshop content to a broader community. Faculty are now comfortable with the web and regularly turn to it for information; thus, the time is right to establish a culture of using the web to share information about teaching and learning. The *On the Cutting Edge* website (<http://serc.carleton.edu/NAGTWorkshops>) plays three important roles.

- It acts as a source of information about the workshop program, with full information about upcoming workshops (e.g., logistical information, information about workshop leaders, participant list) and with application and registration forms. In this capacity, it has streamlined and enhanced our ability to broadly advertise the workshop program and made it easier to collect information from workshop applicants and participants.

- It is a resource for workshop participants before and after their workshop experience. The website is used to help faculty prepare for the workshop by providing materials as well as logistical information. However, the most profound impact on workshop participants has been the use of the website as a repository for full documentation of the workshop and as a place to share materials developed at the workshop and at home as a result of the workshop (see, for example, Teaching Petrology in the 21st Century [<http://serc.carleton.edu/NAGTWorkshops/petrology03>] and Teaching Structural Geology in the 21st Century [<http://serc.carleton.edu/NAGTWorkshops/structure04>]).
- It is a rich site bringing resources developed for and by the workshops to the full geoscience and education communities. This role has been very important in wide dissemination of workshop materials and resources because interest in workshop participation has outstripped space available, and many faculty are not able to attend a specific workshop. The website currently includes topical resources derived from four workshops that have been organized into either searchable collections or tutorials: Teaching Biocomplexity in the Earth Sciences, Teaching Petrology in the 21st Century, Using Data to Teach Earth Processes, and Developing Effective On-line Educational Resources in the Geosciences. We are currently researching the popularity and effectiveness of these delivery formats with faculty.

One of the aims of this project is to expand the network of people who are willing and able to offer workshops, develop web resources, and assume leadership roles in creating future professional development opportunities. Workshops are used to both identify and prepare new leaders to take effective and proactive roles in workshop development. Leadership roles include serving as co-conveners, invited speakers, demonstration leaders, working group leaders, co-conveners of post-workshop sessions at professional meetings, and contributors to the website. Extensive pre-workshop discussions on workshop content as well as strategies to promote active engagement by participants help prepare the workshop presenters for their leadership roles. In selecting leaders for future workshops, including online mentoring activities, we aim for a diverse leadership pool, including those from underrepresented groups, from a broad spectrum of geoscience specialties, and from a wide variety of academic settings.

Program Offerings

Emerging topic workshops

The goal of emerging topic workshops is to catalyze rapid forward motion in geoscience education by bringing together individuals who are making significant contributions to enable synergistic collective action. These workshops form the starting point of a multi-year trajectory of development, with the goal at the end of the process being wide dissemination of information and materials needed for broad inclusion of new content or pedagogy in the undergraduate geoscience curriculum. Geoscientists and educators are invited to recommend topics that address either new methods or new content. Topic selection is based on the importance of the topic in enhancing geoscience education as well as the potential impact of the workshop on moving the topic forward. A key aspect of emerging topic workshops is the development of a plan leading to broad implementation of this topic and the initiation of activities implementing the plan.

Four emerging topics workshops have been offered in the series to date: Teaching Biocomplexity in the Geosciences (2003); Design Principles for Creating Effective Web-Based Learning Resources in the Geosciences (2003); Teaching Geoscience With Visualizations: Using Images, Animations, and Models Effectively (2004); and Geology and Human Health (2004).

Mature topical workshops

These topical workshops integrate pedagogic approaches, research on learning, and up-to-date science. They are designed to bring materials and ideas to a wide audience and promote widespread incorporation into the mainstream. These are our largest workshops, with approximately 70 participants. To date, mature topical workshops have focused on teaching core upper-level geoscience courses: Teaching Petrology in the 21st Century (2003) and Teaching Structural Geology in the 21st Century (2004), with Teaching Hydrogeology in the 21st Century to be offered in 2005. These workshops have resulted in both nationwide discussions and dissemination of content and technique in this critical aspect of the curriculum and in large resource collections on the website to assist faculty in enhancing their courses.

Designing effective and innovative courses in the geosciences workshop

This annual four-day workshop draws 30–40 faculty members each year from a wide variety of institutions who come together to work on designing or redesigning a course that will be taught during the following academic year. The workshop focuses on setting goals that are then used to guide thinking about what the course will accomplish and its design. Participants learn about and consider which teaching strategies will be most effective in the course. Posters presented at the end of the workshop indicate that participants leave the workshop poised and energized to complete the course design or redesign process.

Early career faculty in the geosciences workshop: teaching, research, and managing your career

Offered each year, this 35- to 45-person four-day workshop for faculty in their first four years of full-time teaching combines discussions of teaching methods, management of research programs, and career planning. Participants share ideas and strategies for teaching courses, consider successful strategies for maintaining an active research program and advising/supervising undergraduate and graduate research students, discuss life as an early-career faculty member, and explore ways to balance teaching, research, and service responsibilities. Most participants also visit program officers at NSF the day after the workshop. One of the successful aspects of this workshop is the development of a support network among early career faculty nationwide.

Preparing for an academic career in the geosciences

Offered each year to over 50 participants, this two- to three-day workshop is designed specifically for graduate students and postdoctoral fellows who are interested in pursuing academic careers. Faculty members and administrators provide guidance and information to prepare participants to be more effective teachers, stronger candidates for academic positions, and more likely to succeed in academic jobs. Session topics focus on becoming both a successful teacher and researcher and on the academic job search. Each participant takes home ideas to improve teaching right now and develops a personal action plan. Highlights of the workshop include a panel of faculty from a wide range of institutional types talking about their jobs and a panel focused on the academic job search.

Designing Effective Workshops

On the Cutting Edge workshops have established a reputation as being highly productive learning experiences for faculty. Because designing learning experiences for faculty has much in common with designing learning experiences for students, the workshops are planned using the same strategies we recommend for faculty:

- Determine the goals of the workshop.
- Articulate what the faculty will be able to do at the completion of the workshop.
- Design a program to meet the goals and attain the desired competence.
- Use multiple strategies to evaluate what faculty have learned.

Based on our experience, the following guidelines are used by the workshop leaders in the development of all workshops:

Active engagement of participants during the workshop. Nothing is less effective than a workshop where participants do not participate. Our goal is to give people an opportunity to participate actively in every session using a variety of techniques: small-group discussion, large-group discussion, short problem-solving tasks, involvement of participants in trying out activities, individual or paired work at the computer, and scheduled thinking and writing time.

Modeling effective pedagogy. Participant evaluations tell us that our most successful workshop sessions are those taught with good pedagogy in mind and that our least successful sessions are those where a presenter simply stands up and talks. We continue to explore how to best structure sessions with the goal of using effective pedagogy in all sessions.

Giving participants time to interact and share experience/knowledge. Participants bring valuable experience and ideas to workshops. Structured mechanisms for sharing experiences and expertise are an integral part of each workshop. We support this aspect of the program with unstructured social time that supports the development of networks that will last beyond the workshop.

Providing materials and examples. Examples of how the workshop topics can be applied in the geoscience classroom and field have been particularly valuable resources for participants. We emphasize the template character of the examples, stressing that participants are unlikely to adopt an individual activity wholesale, but rather to pattern some-

thing after one of the examples provided. These materials are available through the workshop websites and disseminated through DLESE where appropriate.

Emphasizing practical applications. An emphasis on practical applications and strategies is an important aspect of effecting change in teaching practice. Workshop participants frequently comment on the value of examples of what works and what doesn't. We provide practical examples.

Giving participants time to make progress on a specific task that connects the workshop topic to their teaching. Time to work individually during the workshop allows participants to reflect and make progress on adapting workshop content to their own needs. This can be effectively supported during the workshop by providing opportunities for participants to work one-on-one or in small groups with workshop leaders. Workshop programs include scheduled work and reflection time for participants.

Making sure that participants leave the workshop with specific plans for future action. Workshops can produce a wide variety of results ranging from changes in teaching practice and development of new learning resources to department-level planning and community-wide action. In all cases, workshop time devoted to planning next steps is critical. Posters or oral presentation of plans have proven to be important motivators in developing realistic plans and in encouraging follow-through. Feedback from other participants facilitated through poster sessions or small-group discussion has also been extremely valuable as a mechanism for sharing practical experience. We emphasize specific plans for future action and use a variety of techniques for presentation and feedback in our workshops.

Requiring some preparation in advance of the workshop. Coming prepared is as important for a workshop as it is for a class. A variety of approaches are used to prepare participants for the workshop, including submitting their goals for the workshop, developing project ideas for completion at the workshop, assembling materials for sharing (e.g., course syllabi, learning resources, and topical papers), participating in pre-workshop discussion, and participating in surveys of participant needs. The workshop website provides support for pre-workshop activity.

Having workshop presenters from a variety of types of institutions and/or disciplines. Participants from a variety of kinds of colleges and universities and from a variety of disciplines within the geosciences greatly enrich any workshop

experience by providing multiple viewpoints and approaches. Classroom experiences vary substantially from two-year colleges to research universities, as does the role or effectiveness of specific content material or pedagogical technique. It is extremely helpful to advancing the collective understanding of effective geoscience education to have breadth of experience in a discussion.

Thorough minute-by-minute planning of workshop sessions. Good workshops that appear to flow spontaneously reflect extensive planning by leaders and a common understanding of the program and its objectives. In the months before each workshop, leaders flesh-out the workshop schedule through a series of email discussions, long phone conversations, conference calls, and, when possible, a pre-workshop run-through. This is especially crucial for modeling effective pedagogy when there are many leaders or presenters.

Does It Work?

One of the biggest opportunities made possible by a large integrated program is the ability to engage a professional evaluator in studying the program. Workshop evaluation has included daily feedback at the workshops, end-of-workshop evaluation, observation and spot interviews at the workshop, and a web-based follow-up evaluation.

All offerings in the workshop series are oversubscribed, with applications coming from the full range of academic institutions, including two-year colleges, four-year colleges and universities, and institutions granting advanced degrees. Workshop participants reflect this range of institutional diversity as well as ethnic and racial diversity beyond that of the geoscience faculty workforce. More than 40% of the faculty participants are female. Of the faculty participants in workshops offered July 2002 through June 2004, approximately 44% are from primarily undergraduate institutions, approximately 44% are from comprehensive or research universities, and approximately 8% are from two-year colleges; the percentages vary from workshop to workshop. Workshop participants have come from more than 250 colleges and universities in 49 states and the District of Columbia.

The workshops are highly rated by the participants. Evaluation data indicate that more than 90% of participants have been satisfied or highly satisfied with their experiences at the workshops, and the overall rating of the workshops is

above 9 (on a scale of 1 to 10, where 10 is very satisfied). While there is some variation in ratings, the level of satisfaction has been similar across type of institution and number of years teaching. Participants report value in four key areas: acquiring new knowledge and skill about the practice of teaching and the integration of education and research, accessing new resources, having the opportunity to affirm their own teaching practices, and networking with new colleagues. Participants also report positive social/emotional outcomes (for example, learning that others share the same problems, building networks that continue beyond the workshop).

Evaluation results (primarily through follow-up surveys) indicate that participants implement new ideas and approaches learned in the workshops in their teaching, return to the website for repeat visits to get new ideas, and recommend the workshops and website to their colleagues. Selected quotes from workshop participants indicate how the workshops have changed their teaching.

"The workshop had a profound impact not only on my petrology course, but all of my courses. I am currently engaged in major revisions to all my courses, including the pedagogies that I employ, as well as assessment and goals. I return to the Cutting Edge websites frequently for information about class activities as well as for links to information on teaching methods." (Teaching Petrology)

"I've been teaching petrology for over 20 years, stuck in the same rut of tradition (teaching it the way it was taught to me)...Spending a week at the workshop thinking about nothing but teaching freed me up to think about the subject in new ways. At the workshop, I turned into a flaming radical on a mission to overturn the traditions of petrology. I'm in the middle of this experiment right now, and I can say without qualification that the class is going better than it ever has, that the students are learning more than ever before, and that the students are more excited about the subject than I have ever seen." (Teaching Petrology)

"I have modified several activities from the website and used them in my classes, and I have also made links to several of the listed web resources. I have con-

tributed several of my own activities to the website. I have passed on many ideas from the workshop to colleagues both at my own department and at other schools. I have referred at least a dozen people to the workshop webpage to view teaching resources." (Teaching Petrology)

"I made a much more concerted effort last semester to make connections between the Earth and Life sciences in the class I teach, which is Earth Systems Science for Educators." (Teaching Biocomplexity)

"A major breakthrough for me was learning how to build a course around a set of goals. This seems like such an obvious necessity, but before the workshop, I did not think in those terms. By setting goals first, everything else follows: content, types of coverage, activities, methods, etc. This realization affects all of my teaching now as I develop new classes or slowly revamp repeat courses." (Course Design)

"I've designed this course using everything I learned at the workshop last summer, and I've thrown my comfortable, well-used teaching style and methods out the window. We're now in week 5, and I've got to tell you, it is one awesome class!" (Course Design)

"I redesigned the entire course and I feel that it was a great success. The course had become an ongoing discussion about methods, content, philosophy of science, how to do research, all rolled up into one. It was exciting. The students were fired up. Their books had actually been used. Binding cracked. Covers and pages dog-eared. It was great. The students were using terminology and asking questions I'd never heard from my prior courses. I do know from the portfolios they created and the course evaluations that this course was much more meaningful and the students learned more than when I taught it before. This has led me to develop a plan to implement a Problem-Based Learning (PBL)-based undergraduate intro geology course next fall." (Course Design)

"I overhauled the content of two courses to be goals based; the goals are very focused on improved stu-

dent thinking and problem-solving and much less on specific content. My classes are better organized. I spend more time with different types of assessment to see if I'm achieving my goals, not just to give a grade." (Course Design)

"The Designing Effective Courses workshop made me develop overarching goals for geology, something I had never done in a systematic way before. I now include those goals in my geology course syllabus, and I have developed similar overarching goals for my meteorology and physics courses." (Course Design)

"This workshop really shaped the way in which I operate as a college teacher. The first thing I do in designing new courses is to develop goals and objectives with higher-order thinking skills in mind. I incorporate active learning even in my larger classes and continue to develop new exercises to incorporate this style of learning into my classes and labs." (Early Career)

"This workshop was a wonderful experience. I would recommend it to any early-career faculty regardless of institution type or background. My History of the Earth class has improved...I have used three new methods I learned about at the short course (gallery walk at first class, students moving to simulate plate tectonics, small-group research panels in lab), each of which has worked well. I've mentioned how I enjoyed the conference and how useful I thought it was to many young colleagues as well as my department chair and others." (Early Career)

In addition to recommending the workshops and websites to colleagues, participants are also sharing what they have learned in the workshop with others. They have reported talking about the project with their chair and others in the department, conducting a university-wide workshop on the new teaching and assessment ideas learned in the workshop, giving presentations to other graduate students in their department, and having one-on-one discussions with other faculty interested following a campus-wide presentation. One participant wrote, "Our department is very fortunate. Four of the six full-time faculty members in our department

have taken this [Course Design] workshop. We are in the midst of major curriculum changes as a result."

The workshop strategies that contributed most to these positive outcomes, based on evaluation results, have been the following: the quality of leaders presenting, easy access to the leaders, opportunities for networking, being able to get away from campus to learn and plan new approaches, and small-group demonstrations and discussions of promising educational strategies. One negative comment that seems to persist is that participants would have liked the workshops to have lasted longer to give them time to learn, plan, and share. We are also working on the evaluation of the web resources and their use, leadership development, and overall project evaluation.

Reflections

While future studies will determine the specific impact that the professional development program *On the Cutting Edge* is having on faculty teaching and student learning in the geosciences, several indicators suggest that an integrated program of workshops and web resources for geoscience faculty is a powerful tool.

The response to a disciplinary-focused workshop series has been outstanding. Focusing on a single topic or sub-discipline in the geosciences provides a meaningful context for discussion of teaching methods and the application of research from cognitive science and education. A major success of the workshop series is its increasing ability to engage research scientists in thinking about their teaching, particularly through workshops focused on upper-level geoscience courses (e.g., petrology and structural geology).

An integrated workshop series has proved to be exceptionally effective in increasing the scope of faculty who participate. Beyond the obvious advantage of an integrated advertising campaign, the series has built associations between advances in scientific research leading to new content in geoscience courses and advances in research on learning and teaching leading to new methodologies for teaching. Similarly, the reputation of the workshop series as a whole has encouraged participants from one workshop to consider a workshop on a topic further from their central interest (to date, almost 10% of participants have taken a second workshop in the series). And not of least importance, the integrated series linked to a website has increased the

visibility of our program. The "brand" *On the Cutting Edge* has become a trusted source among geoscience educators and having a program website increases the effectiveness of discovery on web search engines such as Google.

The power of the website is just unfolding. However, there is no question that we have been able to move workshops to a new level by leveraging our ability to collect, create, and disseminate resources to workshop participants and beyond. Nor is there any question that the website has both simplified and enhanced preparation for the workshop. Important information regarding health, travel, and intellectual property is now routinely collected; participants can find the answers to routine questions regarding travel, logistics, and preparation. After the workshop, participants know where to go to find the program, PowerPoint slides, session summaries, workshop discussion lists, and any follow-up activities or materials. Although the evaluation of the website is just beginning, it is receiving upward of 5,000 hits per month, with two-thirds of the traffic staying longer than a minute and one-half returning for a second visit. Feedback from evaluation instruments and personal contacts suggest that participants find the website valuable and enjoyable.

The integrated workshop series and website are changing the teaching of geoscience faculty. They promote effective and innovative approaches to teaching and incorporation of significant emerging geoscience content in courses across the undergraduate curriculum. Follow-up questionnaire responses include reports by faculty who find their students are more engaged, working more directly with course material, and learning more. We will explore the effect of changing teaching practices on student learning in our overall project evaluation.

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