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A Terrain Transformed:

How *On the Cutting Edge* Contributed to Meaningful Change in Undergraduate Geoscience Education

We do not ask for more of the same effort but rather
for a more productive and rewarding kind of …
education that produces long-lasting results.

—NSF *Shaping the Future* report, 1996

This article is based on a group interview of the project's longstanding PIs—Heather Macdonald, Barbara Tewksbury, Cathryn Manduca, and David Mogk—on June 4, 2019, in Bozeman, Montana; on individual follow-up interviews with each of the PIs; and on reports and web pages cited in-text.

Origins and Outcomes

In 1989, the American Association for the Advancement of Science, or AAAS, released a report called *Science for All Americans* as part of its Project 2061 initiative. The result of a three-year, cross-disciplinary collaboration, the report was an attempt "to come to a valid expression of the view of the science community on what constitutes literacy in science, mathematics, and technology."

Science for All Americans was also a call to arms. "Most Americans are not science-literate," the authors asserted. They described a litany of weaknesses in the U.S. educational system: poorly trained K–12 teachers; onerous teaching loads; outdated textbooks and instructional methods that favored rote memorization and solitary work; and a curriculum that was "overstuffed and undernourished." Positive change, the report argued, would require a shift in educational culture:

> Ultimately, reform is more about people than it is about policies, institutions, and processes… Sensible professionals do not replace their strongly held views and behavior patterns in response to fiat or the latest vogue; instead, they respond to developing sentiment among respected colleagues, to incentives that reward serious efforts to explore new possibilities, and to the positive feedback that may come from trying out new ideas from time to time—all of which can take years.

If the landscape for science education writ large was troubled in the late 1980s and early 1990s, the landscape for geoscience education was particularly bleak. In September 1994, the American Geophysics Union (AGU) sponsored a conference at its headquarters in Washington, D.C., titled *Scrutiny of Undergraduate Geoscience Education: Is the Viability of Geosciences in Jeopardy?* The conference opened with remarks from Gordon Eaton, Director of the U.S. Geological Survey. He challenged the attendees to "rethink [their] missions" as geoscience instructors, pointing out that "the end of the 'Cold War,' the advent of the post-industrial society, deep concern for the environment, and the development of a global economy based on an interdependence of nations" had shifted demand away from geological surveys and resource industries. Eaton lamented the precipitous decline in undergraduate Earth Science majors and the stale curriculum on offer at colleges and universities across the country. Before closing his remarks, he called for a reformed curriculum, better schooling for K–12 teachers, and a broader appreciation of the careers to which study in the geosciences could lead.

Immediately after his talk, a pair of focus papers were presented. One of them was authored by R. Heather Macdonald, then the Dean of Undergraduate Studies of Arts and Sciences at William & Mary and a vice president of the National Association of Geoscience Teachers (NAGT). Macdonald, who had studied geology and education at

Carleton College, and completed her graduate work at the University of Wisconsin, cared deeply about teaching. She was working to refine her pedagogical practices based on sound pedagogy and new ideas, but she found that limited opportunities for pedagogical collaboration meant there was only so much she could learn. Macdonald sought perspectives from other disciplines and began thinking critically about how to introduce those methods and approaches into her own classes. This led her, in the early- and mid-1990s, to write papers concerning alternative, non-lecture-based teaching methods and to convene workshops geared toward improving geoscience pedagogy, especially for new faculty.

Macdonald's focus paper, "Developing Student Career Choices in Geoscience," offered concrete ways to encourage and educate geoscience students about not only opportunities in traditional geoscience careers but also about the ways the study of geoscience could create opportunities in other fields as well. Because she believed equipping students to make informed—and therefore advantageous—decisions would be beneficial not only to the students themselves but to the geoscience community, she advocated for taking a personal interest in students' professional development. The next morning she again emphasized the importance of personal connections in a presentation about the ways in which group work could "personalize" large classes.

For years leading up to and for years after the *Scrutiny of Undergraduate Geoscience* workshop, Macdonald was guided by a principle echoed in the *Science for All Americans* report: that "reform is more about people than it is about policies." She devoted her career to the belief that collaboration, sharing ideas, and personal connections build a strong community, whether that community was an undergraduate classroom or a disciplinary field. Her efforts would not be lost.

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By 2002, Macdonald would be one of four principal investigators on an NSF-funded undergraduate geoscience education program known as On the Cutting Edge (or, more frequently, Cutting Edge). In the fourteen years in which Macdonald and her colleagues—Barbara Tewksbury, David Mogk, and Cathryn Manduca (in 2010 the team grew to include Rachel Beane, David McConnell, Katryn Wiese, and Michael Wysession)—oversaw the program, Cutting Edge grew into a workshop series serving over 3,000 undergraduate educators, graduate students, and post-docs from across the geosciences. Its website had an even broader reach: in the 2017–2018 academic year alone, the site was visited by over 800,000 users.

The program offered an unprecedented and discipline-specific array of tools and resources for staying up-to-date in the fields of geoscience and education research; On the Cutting Edge would become a brand name, synonymous with high-quality workshop experiences that helped participants increase student learning in their classrooms, learn from their colleagues, and strengthen the foundations and first steps of their careers.

The name was also synonymous with a carefully organized, navigable, up-to-date, and peer-reviewed online resource for educators, students, and the geoscience-curious public alike.

David Mogk, looking back on the origins of Cutting Edge, said the PIs found themselves in the right place at the right time—that a combination of research on effective pedagogy, an enthusiasm for the possibilities of digital learning, and a common understanding that the status quo in science education was neither sustainable nor desirable created a unique opportunity for the Cutting Edge project leaders. The point is a good one, but it was also essential that he and his colleagues shared important values and principles that allowed them to work long and productively together. For the duration of the program, they remained interested and invested in the members of the undergraduate geoscience community: who they were, what they needed, and how they could be served.

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Two other future Cutting Edge PIs were at the 1994 *Scrutiny of Undergraduate Geoscience Education* conference. One of them was Barbara Tewksbury, a graduate of St. Lawrence and the University of Colorado, a professor at Hamilton College, and then an acquaintance of Macdonald's—both had been involved with NAGT's executive committee, and both would go on to be presidents of the organization. Tewksbury gave a presentation Saturday afternoon called "Strategies for Teaching Introductory Geology to Both Majors and Non-Majors: Connecting the Geology of Africa with Pre-Historic, Historical, Political, Cultural, and Economic Evolution." With the support of an NSF grant, she'd developed the course to teach geology through the lens of non-science topics (she still teaches a version of the same course today). Tewksbury's interest in teaching strategies went back to her college years at St. Lawrence, where she studied in the Earth Science Curriculum Program designed in part by William Romey. While admitting that the program didn't work for everyone, Tewksbury said Romey taught her that students were, in the end, responsible for their own learning, and that, as she put it, "You could make something more out of the average classroom experience." The desire to facilitate that *something more* in the classroom led Tewksbury to graduate school, with the goal of becoming a faculty member.

The early years of her career as a professor would soon build on what she had gained from Romey and the innovative materials she had developed herself. In the early 1990s, Tewksbury shared a grant with a high school Earth science teacher, Robert Allers, to run in-service training for other high school Earth science teachers. Working with Allers, she said, exposed her to the world of pedagogical research: "I realized there was a literature out there on how to help students learn better, and how to help put more effective responsibility on students for their own learning," she said. "It was talking

with [Allers] about what he would do with these students, with this content, that was a light-bulb moment for me."

Learning about the scope of literature on pedagogy made Tewksbury re-think the way she was teaching: "It was the first time I asked myself not, *What do I think ought to be in the structural geology course?* but *What do my students need out of a structural geology course?* That's a profound difference. I completely re-designed my class by thinking, *Who are my students? What are they going to do with structural geology in the future?*"

She also began re-thinking how she assessed her students, and moving away from a "high-stakes, high-stress" exam at the end of the term: "I always cared whether someone could *do* structural geology, not whether they could do it timed," she said. One consequence of this way of thinking was asking, in her words, "What do I want students to be able to *do*?" to drive her development of the Geology of Africa course. With this question and this course, Tewksbury said, she more or less solidified her approach to pedagogy.

Tewksbury was not alone in her recognition that the professional geoscience literature tended to exclude pedagogical issues; she later remembered conversations with other members of NAGT's executive committee—such as Macdonald—about the importance of effective teaching. Tewksbury began offering workshops on innovative teaching techniques across the country and internationally; as of 1995, she and Macdonald were co-PIs on an NSF grant to run a Distinguished Speaker series for NAGT. The topic of the series? Innovative teaching and curricular reform.

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The other future Cutting Edge PI in attendance at the *Scrutiny* meeting was David Mogk, a graduate of the University of Michigan and the University of Washington, a geology professor at Montana State University, and a member of the conference's steering committee. In "Towards Training a New Generation of 'Citizen-Scientists'," Mogk encouraged his audience to make use of "driving questions" to encourage exploration and reflection in the classroom; to have students find evidence themselves to work with those driving questions; and to incorporate serviced-based learning projects in order for students to apply their knowledge. In fact, Mogk's first suggestion directly quoted a recommendation from the *Science for All Americans* chapter on educational reform: "Start with questions about nature."

It was a combination of reading *Science for All Americans*, and teaching a course called "Texts and Critics" at the Montana State University Honors College, that Mogk would later credit as influences on his teaching philosophy and practice. Both the Honors College pedagogical methods and the *Science for All Americans* report valued methods in which students were not fed facts and principles but encouraged to test their knowledge. "People Learn to Do Well Only What They Practice Doing," reads a heading

in *Science for All Americans*. Mogk had taken that message to heart, and wanted to provide more than a "rocks-in-a-box" style of geoscience education.

Starting in the early 1990s, Mogk advocated for a discipline-wide commitment to high-quality education, one that would build the strength of the geoscience community not on the hiring patterns of extractive industries but on an informed and impassioned commitment to student learning. This advocacy work led to an invitation to co-convene the *Scrutiny* conference. After the conference, he wrote the proposal for an NSF-funded workshop at Smith College called "Teaching Mineralogy." Though Mogk didn't end up running the workshop because of a conflict of interest after he took a position at NSF, his planning work contributed to a workshop that organized collaborative discussions around course goals, student needs, and teaching methods.

Mogk's interest in teaching was on what he called a "local" level—it affected the students in his classes, and the students of attendees at workshops like Teaching Mineralogy. He had a global reason for doing this work as well: his and his colleagues' appreciation of and vital knowledge about the Earth "was simply not getting out. What the early reports showed," he continued, "was we were being rendered irrelevant in the public discussion. The geoscience voice was not being heard. We had to do something."

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The final section in the companion report to the *Scrutiny* conference explained that while the meeting had "generated excitement among the participants," the community still had to face a pressing question: "Where do we go from here?" Collaborative effort and communication would be "essential as an attempt is made to improve undergraduate geoscience education. We must also keep in mind," the report cautioned, "that while enthusiasm is great, resources and time are limited."

The report does not make mention of another limitation: who was able to attend the conference—and who wasn't.

A Call to Shape the Future—and a Response

Cathryn Manduca had wanted to go to AGU's *Scrutiny of Undergraduate Geoscience Education* conference, but she couldn't attend the workshop. Manduca, who had studied geology at Williams College and the California Institute of Technology, had just completed a three-year teaching stint at Carleton College. As of the *Scrutiny* meeting, she was caring for her young children and working for the Keck Geology Consortium, an association of geoscience departments at liberal arts colleges (there were twelve member colleges at that time; the number is now seventeen). Manduca's responsibilities included coordinating inter-institutional research projects, Keck's annual

symposium, and a workshop series; she credited these experiences with revealing the power of collegial interactions, collaborative work, and idea-sharing to create positive change. As the Internet developed, Manduca became skilled in supporting teams with members from institutions across the country. “I was never scared of engaging faculty from across the country in working together after that,” she said.

Still, she deeply regretted missing the *Scrutiny* meeting. She later said, “I remember thinking, *I can’t go to this, and that may be the end of my ability to participate in this enterprise.*”

In fact, Manduca was nowhere near the end of her participation in the enterprise of reconsidering, reshaping, and improving the landscape of geoscience education. Soon after the *Scrutiny* meeting, she would start attending Project Kaleidoscope (PKAL) events. At the time, PKAL was an NSF-funded undergraduate science and mathematics education community founded by Jeanne Narum. Narum’s vision involved collaboration and resource-sharing to build a community of practice; the workshops she led were designed to leave participants with ideas and plans they could immediately implement. Manduca—and Macdonald, who was also involved in PKAL—would later credit Narum for shaping their ideas about what made for a successful, useful workshop. Said Macdonald, “Seeing how she ran things was influential … She was always having you think about what you were going to do next,” after the workshop was over.

Even as Manduca’s participation in the enterprise of undergraduate science teaching increased, more dire warnings about the condition of science education in the United States were arriving, most notably in the form of an NSF report called *Shaping the Future*. The report had been commissioned in 1994 by the Assistant Director for Education and Human Resources at the NSF. (Mogk, who was a program officer at NSF during this time, helped represent the geosciences in the report.) The findings included this charge:

> America’s undergraduates—*all* of them—must attain a higher level of competence in science, mathematics, engineering, and technology. America’s institutions of higher education must expect *all* students to learn more SME&T, must no longer see study in these fields solely as narrow preparation for one specialized career, but most accept them as important for every student… In an increasingly technical and competitive world with information as its common currency, a society without a properly educated citizenry will be at great risk and its people denied the opportunity for a fulfilling life.

Meaningful advances in what was then called SME&T education had been made, *Shaping the Future* asserted, but the agenda for SME&T education was “broader and more urgent” than it had been before. The report urged state and federal governments, industry leaders, schools of higher education, and the professional community to

address the problem: “We do not ask for more of the same effort but rather for a more productive and rewarding kind of undergraduate SME&T education that provides long-lasting results,” it stated.

Given their backgrounds, experiences, and proclivities, neither Macdonald, Tewksbury, Mogk, nor Manduca were surprised by the contents of *Shaping the Future*. “We were already enlightened,” Mogk would later say, about his and his collaborators’ keen awareness of the nature of the problems in science education.

When *Shaping the Future* came out, Mogk was a program officer in NSF’s Division of Undergraduate Education (DUE), where he was collaborating with Frank Ireton, the Education Director at AGU, on a proposal for an Earth science education workshop. Manduca was brought on as a convener of the workshop, called *Spheres of Influence*, by Ireton, whom she’d met at a Keck workshop and who valued her work with the community of liberal arts colleges.

Spheres of Influence was designed to respond to both *Shaping the Future* and the National Research Council’s *From Analysis to Action* report, and it took place in November 1996, six months after the NSF *Shaping the Future* was released. Tewksbury and Macdonald both served as panelists at the conference; Tewksbury’s panel addressed the question “How should we teach Earth system science?” and Macdonald’s panel responded to“How can we change the academic culture to promote reform?”

The workshop’s resulting report was called *Shaping the Future of Undergraduate Earth Science Education: Innovation and Change Using an Earth System Approach*. This explicitly disciplinary response was meant to benefit the Earth science education community in two ways: first, recent initiatives to reform teaching practices in the disciplines of calculus and chemistry had the conveners hoping for a similar, NSF-funded curriculum reform in the Earth sciences. The second benefit would be increasing the visibility, relevance, and funding for geoscience education through the NSF directorate for Education and Human Resources (Division of Undergraduate Education) and Directorate for Geosciences (Divisions of Earth Sciences, Ocean Sciences, Atmospheric Sciences, and Polar Programs), all of which were operating with relatively small budgets.

Both of these potential benefits were related to an ongoing and large-scale shift in geoscience research: “Our science as a discipline was moving toward convergence as an Earth system,” Mogk said. The Earth science *Spheres of Influence* conference, he explained, was “the first time we got those sub-disciplines in the same room to explore shared interests in Earth system science and education.”

The conference was also experienced by at least one participant as a personal and meaningful instance of inclusion. Manduca, who had been so disappointed to miss the *Scrutiny of Undergraduate Geoscience Education*, was now interacting in person

with members of the Earth science education community she'd only heard about: planning and participating in this event, she said, made her feel she'd "peeked up over some wall. All of a sudden I had all these people, because they'd made a community."

She had found the community with which she hoped to shape the future.

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The day after the conference ended, Mogk and Manduca met for lunch at the India Polo Club on Connecticut Avenue. It was the sort of lunch meeting that would allow the conveners to look back on the conference and consider next steps.

The NSF would be funding a digital library initiative, he told her, at least in part in response to its *Shaping the Future* report, which had made a recommendation that NSF "explore the establishment of a national electronic system for validating and disseminating successful educational practices." A digital library was of particular interest to NSF because, although it had been funding education-related projects, it did not have the means for widely disseminating findings and resources. Its Digital Libraries Initiative was to include a National Science Digital Library (NSDL), but in the short run, a digital library for the Earth sciences could serve as a prototype for the larger, national library. Already, Mogk was collaborating with Bob Watson, Lee Zia, and Dottie Stout to further the cause of digital libraries at NSF.

Interested in joining the ongoing efforts, Manduca was soon working alongside Dottie Stout and Mike Mayhew, another champion of the cause of digital libraries at NSF. In 1999, at Coolfont Resort in West Virginia, Manduca was a convener—along with John Snow (University of Oklahoma) and Donald Johnson (University of Wisconsin)—of the *Portal to the Future* workshop. The goal of the workshop was to develop an action plan for a Digital Library for Earth System Education (DLESE), and the results were published in June 2000 as the DLESE Community Plan. Manduca and Mogk served as co-editors of the report, which situated itself against the backdrop of the NRC's National Science Education Standards (1996) and NSF's support for the Digital Libraries Initiative. (It's also worth noting that the community plan built off of a "preliminary vision of a digital library for the Earth sciences … presented by Mogk and Zia.")

The tone of the DLESE Community Plan was enthusiastic—it gave a sense of optimism at the opportunities current technologies provided. The Plan began:

> Earth Science education is entering an exciting and challenging new era as significant changes are being made in the ways teachers and students learn about the Earth … There is a growing awareness of the need to integrate 'best' instructional practices with accurate and reliable scientific content. At the same time, new information technologies provide direct linkages between people (e.g., educators, researchers, and the community at large) and

> information about the earth (e.g. instructional materials, data sets, images) that make new ways of learning possible.

The report detailed the ways DLESE would provide "high-quality materials for instruction"; "access to Earth data sets and imagery"; and "discovery and distribution systems" that would make materials and resources easy to find; would "support services to help users effectively create and use materials in the DLESE 'holdings'" and build "communication networks" that would "facilitate interactions and collaborations across all interest of Earth system education." It's no coincidence that the DLESE report was called a "Community Plan"—the vision for the digital library was about fostering a robust educational community in the Earth sciences.

By the time the DLESE Community Plan came out in June 2000, the University Corporation for Atmospheric Research, or UCAR, had received funds for the digital library; the Plan noted that the program center would be at UCAR, which would oversee and develop the library's technical infrastructure. For a time, Manduca worked with digital library funds for community services, and Mogk helped develop the digital library's connections.

Mogk and Manduca ended formal collaboration with UCAR after Cutting Edge was underway, but the valuable lessons, experiences, and connections they gained from DLESE benefited the Cutting Edge project for years afterward.

Putting the Pieces Together

The Cutting Edge team comprised members who had worked together in overlapping ways but never collaborated on a single project. As of when they applied for their first Cutting Edge grant together, Macdonald, Tewksbury, and Mogk had offered workshops for faculty early in their careers; Macdonald and Tewksbury had offered workshops on course design and innovative teaching strategies; Manduca and Macdonald had collaborated on PKAL and quantitative skills events; and Manduca and Mogk had worked together on efforts including the DLESE workshop and report and the *Spheres of Influence* conference. And as far as their grant application went, it could only help their case that a number of their projects had already been funded by NSF: the NAGT Distinguished Speaker series that Tewksbury and Macdonald organized; the Teaching Mineralogy workshop for which Mogk wrote the proposal in 1996; NAGT workshops on innovative teaching strategies and course design (Macdonald and Tewksbury); NAGT workshops for early career faculty (Macdonald, Tewksbury, and others); the *Spheres of Influence* conference; and the DLESE planning meeting. These

past instances of funding helped make the case that the group's collective expertise in both digital libraries and workshops made them ideal figures for a combined approach.

In turn, a years-long grant supporting an integrated website and workshop program was ideal for the PIs: better to put their efforts toward a large, multi-year program than continue to write proposals for single workshops.

The first of what would be three Cutting Edge grants began on January 1, 2002, and was titled "Collaborative Research: Combining Real and Virtual Professional Development for Current and Future Geoscience Faculty." Its abstract began:

> The National Association of Geoscience Teachers (NAGT) and the Digital Library for Earth System Education (DLESE) is offering a professional development program to improve the quality of undergraduate geoscience education. The program is designed to enhance the participants' content knowledge in emerging fields and promote exemplary teaching practices; develop effective on-line resources to support existing workshops; provide electronic versions of workshops to extend the influence of the workshops; and develop an active cohort of educators involved in further dissemination.

The abstract went on to describe the program's professional development offerings: workshops on topics still "emerging" in the discipline and in pedagogy, as well as more "mature" themes such as course design and managing the first steps of an academic career.

The abstract made clear that the website would be a crucial piece of the program's planning and reach: "Integration of workshop planning and web-resource development are combined in a unique on-line resource aimed at extending the workshop experience far beyond those who attend the face-to-face workshops and beyond the lifetime of the grant," the PIs asserted. By offering carefully-crafted workshops that built off of prior workshop successes and a community-authored site that collected and presented resources from workshop groups, Cutting Edge sought to offer a singularly useful collection the entire undergraduate education community could use to learn and grow together.

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A brochure from about 2006 described the four categories of workshops Cutting Edge offered; these categories were influential for the duration of the program. Emerging themes workshops responded to developing research on both the Earth system and learning by putting those topics "on the fast track—moving them from areas of isolated early activity … to widespread implementation in undergraduate geoscience courses." Teaching the Core workshops (also often referred to as "Teaching X") engaged "research scientists in thinking about the way they teach core courses," and

were guided by “cognitive science and research on learning to guide their teaching.” Course Design workshops helped participants design student-centered courses in which the goals were to support students in developing particular skills and giving them the tools to “think for themselves in the discipline after the course is over.” Finally, the Career Preparation and Management workshops (which included “Early Career" workshops for faculty in their first few years of tenure-track positions and “Career Prep” workshops for graduate students and post-docs) were designed to “foster the next generation of geoscience educators and develop the leadership needed to ensure the overall health and vitality of geoscience education.” These workshops—and others in person and, as the program progressed, online—encouraged participants to share ideas for teaching, helped them build their professional networks, and provided insights about balancing personal and professional responsibilities.

Across Cutting Edge workshops, whether they were for graduate students or faculty members ten years from retirement, was the philosophy that effective workshops *engaged* participants. Macdonald referred to this approach as “modeling strategies you want [workshop participants] to use in their classrooms”; Tewksbury emphasized that participants familiar with Cutting Edge workshops knew they weren’t going to learn from “talking heads” —that instead, they would be given space to share their expertise with a group, learn from one another, and make valuable progress on applying what they were learning to new materials for their own courses.

Cutting Edge workshops also operated on an assumption that current and future faculty members could not be handed a curriculum; the point of sharing materials was never blind adoption. As Manduca put it, “the context in which they’re teaching, and the mechanisms by which they implement that curriculum, are too important” to be standardized. “So,” she continued, “how do you help faculty make good choices and be more effective, more efficient?”

An interesting—and productive—complexity to the philosophy driving Cutting Edge is that while it’s unproductive (and uninspiring) to hand faculty a curriculum and expect them to be effective in the classroom, it would also be unhelpful to expect them to find their own way as educators without examples, specific ideas, and inspiration. Mogk put it this way: “We have always been about not reinventing the wheel. We’ve tried to take the practitioner’s wisdom and put it in a public place so everyone doesn’t have to rediscover it on their own.”

Gathering and disseminating teaching materials on the website meant much more than collecting those materials and storing them in one place: on a basic level, it meant building and supporting a culture of online, educational resource-sharing. In the early 2000s, however, there was no precedent for organizing a community’s teaching materials online. A mode for disseminating discipline-specific articles on education existed in the form of the then-*Journal of Geological Education* (now the *Journal of*

Geoscience Education), but *JGE* focused on noteworthy and novel contributions more than on wisdom gained from experience, and very rarely published teaching materials. While valuing the importance of *JGE* articles, the PIs wanted to give practitioners virtual access to a large-scale, ongoing, collegial conversation about courses, activities, and assessments. Considerations of this goal permeated social, technological, design, and philosophical elements of the Cutting Edge program.

Besides navigating technological tools, the program's leaders had to make the process of building the site's collections meaningful for workshop participants. Program leaders had to answer questions like "What do people expect from a workshop?", "What sort of conversations and resources come out of workshops?", and "How can we capture those conversations and resources and put them on the website?" Providing context for teaching materials was key for building collections that reflected practitioners' wisdom. "Lots of times we had [workshop participants] write essays to accompany submitted courses or activities," Manduca said.

The site was an essential resource for teachers like Macdonald and Tewksbury, who in their early careers did make connections, access research, and hone effective teaching methods, but did so with great effort, and never with the insights of quite so many experienced practitioners to guide them.

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Over and above the philosophies that led the four PIs to actively engage participants and model good teaching strategies, there were a number of other features consistent across Cutting Edge offerings, all of which amounted to what Tewksbury called the "Cutting Edge way"—an integration of philosophy and execution that was unique to the program.

Especially in the first years of the program, two or more PIs collaborated on most workshops; consequently, the methods of running the workshops, adding resources to the website's collections, involving and motivating participants, and setting the tone of the workshops were consistent across program offerings. Examples of the Cutting Edge way ranged from daily practices to overarching goals. Daily "road checks" designed to find out about participants' ongoing experiences (the concept was attributed to Cutting Edge's evaluator, John McLaughlin) allowed workshop conveners to address anything they reasonably could, from the temperature in the room to the makeup of working groups. Structuring workshops to ensure that participants left with something they could implement in their classrooms meant that leaders gave participants time to use the ideas, concepts, and research presented to make progress on their teaching materials; in the case of Early Career and Career Prep workshops, participants left with an action plan they could use to advance their careers. Workshop conveners planned carefully for each workshop—"We would get the leaders together the day before the workshop, and go practically minute-by-minute through the schedule," Tewksbury explained—ensuring,

as any skilled educator would, that talks, tasks, and transitions were clearly presented and well timed. There was a general emphasis on adaptation rather than wholesale adoption ("Ask presenters to emphasize the template character of their examples and to offer ideas for adapting an activity," the "Design Your Workshop" Cutting Edge webpage advised). And there was an overarching understanding of the essential role the website played in all of this—that it was a resource to be used and added to at stages before, during, and after the workshop; that it represented the wisdom of the gathered practitioners, and was a means of extending the impact of that wisdom.

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The third Cutting Edge grant began in 2010. Its abstract began, "This project is … continuing to provide a comprehensive, discipline-wide professional development program for current and future geoscience faculty." The language pointed to the holistic approach the program applied to its original and ongoing goal of improving the quality of undergraduate geoscience education: the program's components served undergraduate educators at all points in their careers and by meeting a range of needs. All workshops emphasized the importance of effective and research-supported teaching methods. They were also tailored to be helpful to their particular audiences: a participant in an Early Career Faculty or Career Prep workshop, for example, would benefit from learning about active teaching in an environment that expanded their professional network and gave them tools to write effective proposals. A tenured faculty member would be best served by discussing the finer points of their approach to a particular subject with colleagues in a Teaching X workshop.

The abstract goes on to include specific goals, such as increasing the participation from two-year colleges, expanding the website's community-authored offerings, and "incorporating a full research and evaluation program" before ending on this note: "The project is developing and disseminating best practices for the geosciences, however, many project activities are also being transferred to other STEM disciplines through publications, presentations, workshops, and through collaborations developed with SENCER and other organizations." Developing links between research on learning and teaching practice was a crucial piece of the Cutting Edge program. Professional networking between these fields, particularly at Emerging Themes workshops focused on pedagogy, led to valuable relationships and a number of additional grants. As Manduca described it, Cutting Edge was not only about making sure research was more widely used: it was also about fostering a healthy connection between practitioners and researchers, one in which the flow of ideas went in both directions—a topic this article will return to.

Communities do not respond to being fixed; knowledgeable networks do not like being told. The wisdom in Cutting Edge lay in its emphasis on engagement, on connections and support, on demonstrating over and over that within the community

was a wealth of valuable experiences and insights, and on fostering vibrant connections between a teaching and research community. These emphases were readily apparent in workshop gatherings and are still apparent on every page of its community-built site.

Innovations and Breakthroughs

The overarching consistencies in the workshops and online offerings were balanced with continual adaptation to improve the strength and reach of the program. Some advancements in the program involved adjusting workshop design based on observations about participants' behavior before, during, and after workshops; many others were made in response to developing technology.

To reiterate a characteristic that set the Cutting Edge website apart from, say, a broadly-defined, if discipline-specific, digital library, the site was made for and by the community in an ongoing and iterative process. Over time, Cutting Edge developed and improved strategies for collecting and sharing these resources. The principles behind these strategies have been discussed; this section will, in part, describe how technological advances, coupled with design shifts, supported strategies for soliciting and sharing materials, and for building reviewed collections.

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From the beginning of the program, the website was designed to share materials from workshops. This objective was partly inspired by paper workshop notebooks that had been provided to workshop attendees, such as those at the Teaching Mineralogy workshop in 1996, so they could have a record of the ideas discussed at the workshop and activities they could adapt. Sharing resources on the internet, though, presented new challenges and required dramatic changes to the paper model. It required a cultural shift: educators had to grow accustomed to adding their materials to the website as well as accessing it when they sought an idea or example. It also required developing new processes that would make a culture of online sharing feasible.

Cutting Edge put substantial effort into learning who was using the website and what they needed. These efforts yielded the insight that users cared less about accessing individual workshops by date than they did about learning about a topic in geoscience or pedagogy or accessing a particular kind of resource. As a result, the website was dramatically re-structured to effectively meet its users' needs by emphasizing topics over workshops. Users could still navigate to individual workshops, but the overarching organization was based on themes in geoscience and education.

In reflecting on the website's design, Tewksbury said, "We weren't trying to be the be-all, end-all of Earth science content… My sense when we were originally writing the grant was that what we wanted to do was have a bunch of narrow and deep [topics]

that had connections between them." Mogk pointed out that from the beginning the intention was to allow users to navigate horizontally and vertically; that is, to take a "deep dive" into a particular topic in geoscience, as well as find related teaching assignments and pedagogical information.

Over the years the website's topical offerings grew alongside the workshops; new workshop topics became new website topics, and existing website topics were added to and expanded on thanks to new material from more recent workshops. The program leaders, in collaboration with website designers, were building a website that reflected the ideas and innovations of an increasingly interconnected and invested educational community.

The development of a successful website was facilitated by the Science Education Resource Center (SERC) offices at Carleton College. Manduca was responsible for establishing SERC, which developed out of her need for a place to literally and figuratively house the grants she was working on, including Cutting Edge. Cutting Edge funds allowed her to hire a programmer, Sean Fox, who proved instrumental in building a content management system, or CMS, for Cutting Edge at a time when content management systems were rare. (As of 2019, he remains the IT director at SERC.) Manduca described the night-and-day difference between previous experiences she'd had with website development—when she had to work with a programmer every time she wanted something on a website changed—and with the CMS, which was a tool members of the Cutting Edge team and even workshop participants could use to update the website. "That CMS, even in its early days, made it possible for any one of us to build a decent webpage," Tewksbury said. New pages could be built using the templates of existing pages—yet another example of how the program continually adapted and refined existing materials and processes.

Mogk, Macdonald, and Tewksbury were quick to point out that the services that Fox—along with the SERC staff—provided to Cutting Edge were wide-ranging and essential. "We could not have done it if we didn't have Cathy [Manduca] and the SERC office and the staff," Tewksbury asserted. As full-time college faculty, she, Mogk, and Macdonald had myriad teaching, research, and departmental responsibilities: "[SERC staff] weren't side-tracked by a student walking in your office or the next course you've got to teach," she added.

Advances made in collaboration with Fox and the SERC team allowed Cutting Edge to streamline the collection of workshop participants' materials and make those materials useful to the community in a variety of ways. Activity Sheets, for example, allowed participants to submit information about their teaching materials to the website and edit the resulting page. Mogk summarized the questions on these sheets by asking, "What are the goals? What are the assessments? How is this situated within your class? Who's your audience? Is it a capstone, summative activity? Is it an introductory

activity?" Fox's new technology meant these items could then be easily tagged, sorted, and searched using vocabulary developed by the workshop leaders and participants. In addition to helping Cutting Edge accurately describe and organize an activity, the Activity Sheets helped individuals submitting their materials think more critically about the pedagogical underpinnings of their own submissions.

Offering the community tools to share and access resources was important to Cutting Edge leadership; so was offering resources that had been vetted. A peer-reviewed collection of instructional materials had been called for in NSF's *Shaping the Future* and was echoed in the Earth science community's response to that report. The review practices Cutting Edge used for educational material built on criteria developed in DLESE planning as well as the work of the National Science Digital Library (NSDL); the California State University MERLOT program; and Climate, Literacy, Empowerment and Inquiry (CLEAN) program; and a rubric developed by Kim Kastens (a Cutting Edge workshop participant and leader). There were also review models within the program itself: Course Design workshops had for years involved materials and templates for review activities.

On the topic of implementing Cutting Edge review practices, Mogk said, "There were a couple of … experiments in how to do this." These "experiments" included incorporating review as part of workshop, requiring review leading up to workshops, and adding a review component to virtual workshops. The longest-running model for completing review has been "review camps," in which hundreds of reviews can be completed at a designated time and place using an online review system Fox built. This model is currently being sustained as a part of the Earth Educators' Rendezvous gathering: reviewers arrive a day early to do their work, and in return receive a travel stipend for the Rendezvous. The success of the review process is evident in the fact that other undergraduate Earth science education programs have availed themselves of this capacity for review.

Like virtually all of the community effort that went into developing Cutting Edge's online resources, review served as a form of professional development. Reviewing the teaching activities of peers and colleagues according to a clear rubric led reviewers to reflect on their own activities. Understanding the value of these efforts, Cutting Edge leadership sent out personalized letters to acknowledge reviewed activities. In doing so, they hoped to normalize the idea that pedagogical contributions were as valuable as more traditional, academic contributions.

Collecting the activities, categorizing them, and having them held to a high standard of review took years of organizing and widespread effort. The result speaks for itself: the Cutting Edge site now holds some 2,500–3,000 reviewed activities. It's the largest reviewed activity collection in any STEM discipline.

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Another goal from the start of the program was virtual workshops. Though the goal was more than met—eventually, online offerings included workshops as well as webinars and journal clubs—there was much learning to be done along the way. Cutting Edge ran some of the earliest virtual workshops of its kind, so every early online offering had an element of experimentation. What made for a successful experience? The PIs refined their answers to this question over the years, and during the third grant, the newer PIs offered valuable help in continuing to answer this question.

Course Design was the natural choice for the first online offering because of how much independent work time was structured into the workshop: participants were regularly given time between sessions to work on their own courses before returning to the group to give and receive feedback. Based on the known strengths of the in-person model, the first iteration of the online Course Design workshop in 2005 operated much like an in-person, four-day Course Design offering. Workshop members had to be available at particular times and were given blocks to work independently. Tewksbury and other workshop conveners then saw the advantage to giving participants more time to reflect between sessions, so the workshops were spread out over a few weeks. When participants started expressing an interest in face-to-face introductions, a new model involved a Course Design kickoff at a GSA meeting followed by virtual engagement. The final Course Design workshops were topic-specific, with the idea that people working on the same type of course could offer each other the most meaningful feedback.

Other virtual workshops evolved in similar ways, though not along an identical path. The Emerging Theme workshops, for example, came to a two-week structure with more working time between synchronous online meetings; the Emerging Theme offerings also grew to include virtual journal clubs on educational and cognitive science themes.

The modes by which participants interacted in online workshops changed along with developing technologies. Tewksbury described an early iteration of a virtual workshop as a setup where participants called in to the same number at regular intervals before breaking off to do assigned tasks; over time, participants could meet in virtual meeting rooms, take part in threaded discussions, and more easily access and comment on each other's contributions.

It should go without saying that different models of virtual workshops—like different models of in-person workshops—offered distinct advantages and limitations. In all cases, Cutting Edge sought to serve its participants, and the wider community, as well as possible. Any changes in approach were based on the idea that—as the "Design Your Workshop" webpage put it—a workshop should be "a shared enterprise among conveners and participants." The goal was always how to best reach, engage, inspire, and build community.

Macdonald reflected that, though she was initially skeptical about virtual workshops because she valued the nonverbal cues she could glean from face-to-face interactions, she learned that online workshops offered opportunities not possible in a face-to-face setting. For example, if managed correctly, a group could address a few threads of conversation without talking over one another. Additionally, the whole group could benefit by witnessing an exchange between a facilitator and a participant—the sort of "office hours" conversation that usually happens one-on-one.

Other design shifts also reflected what the PIs learned about the habits and needs of participants. Early on in the program, the PIs thought that participants would stay in touch and grow together after workshops, whether online or in person. But almost none of the workshop groups clicked in that way (with the exception, Manduca pointed out, of the Mineralogy group)—what the PIs learned in the evaluation process was that, post-workshop, participants tended to strengthen or build their own local communities. The PIs also learned not to ask participants to submit materials after the workshop was over—despite all good intentions, participants were focused on the immediate demands of their jobs, making follow-through after the workshop not reliable enough to build robust teaching collections.

Overall, the Cutting Edge program was devoted to continually improving both the workshop experience and the capacity of workshops to create resources to serve the larger community. The efforts of the program's leadership, and the buy-in from the community, had impact on a national scale; this impact could be, and was, assessed.

Evaluating Impact, Advancing Research

Evaluation on both a micro- and macro-level remained important for the duration of the program. It allowed the project's leaders to understand if—as Manduca put it—"what we were doing was what we thought we were doing," and to thereby refine Cutting Edge in response to what they learned.

A logic model was an early and essential example of using evaluation to understand the program and its impact. At the outset of the first grant, the PIs met with their external evaluator, John McLaughlin, who worked with them to develop a logic model. Although logic models are now a common part of projects of this size and scope, at the time they were relatively new, and—not unlike the good fortune of working with Fox for the website—the PIs were fortunate to work with McLaughlin, who was skilled at developing logic models. The logic model changed over the years, and a theory of change was developed midway through the Cutting Edge program. Each revision or new direction for the logic model represented the program's evolution and the maturation of its leaders' thinking. The logic model also exemplified the two-way flow

between research and practice: research shaped the development of the logic model, and the logic model shaped further research.

Another important evaluation tool for Cutting Edge was a national survey of undergraduate geoscience educators. Long before the explicit focus on community of practice, and on a theory of change involving individuals and the large community, the PIs put in place a plan to understand the size, scope, and practices in the community. While the group's first logic model was being created, Tewksbury suggested a national faculty survey.

The survey has been offered four times: in 2004, 2009, 2012, and 2016. The surveys, guided by logic models, asked about more than general teaching practices. They were designed to reveal where faculty learned the practices they were implementing in their classrooms and in what ways they were contributing their knowledge back to the larger community. Because teaching practices in different courses would make it challenging to meaningfully compare results, the survey focused on one course that faculty had taught in the last two years.

Cutting Edge evaluation also evolved in line with a shifting emphasis at NSF and within the broader research community: there was a move away from focusing on project evaluation to a combination of evaluation and research. Cutting Edge initiated research teams for classroom observations, assessment groups, and to analyze survey data. The Classroom Observation Project, initiated in 2011, created a shared rubric for observations using the Reformed Teaching Observation Protocol (RTOP). The work of assessment groups proved outside the scope of Cutting Edge, though the team's strategies have been adapted for use by InTeGrate. The survey research group is, as of this writing, developing research papers based on survey data. Manduca called all three research teams "incredible and novel examples of the community using data to understand geoscience education and the program's impact while developing research capacity."

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Evaluations and feedback during workshops meant that conveners were regularly learning about attendees' experiences. Macdonald noted that this care for and interest in the day-by-day experience of participants offered valuable information and could lead to mid-workshop adjustments. Additionally, end-of-workshop evaluations meant Cutting Edge could incrementally improve its offerings by responding to attendees' overall assessments. In addition to these evaluations, detailed follow-up surveys and post-workshop interviews provided data about teaching practices sometimes years after workshop participation; these data improved the program and supported additional research.

Cutting Edge's impact on research has been far-reaching. SERC, which originally served Cutting Edge and just a few other projects, has now supported more than 100

projects related to STEM education. The Cutting Edge model and approach, that is, shaped the structure and design of SERC, which in turn offered expertise and know-how to a wide array of other projects dedicated to research, education, knowledge dissemination, and community involvement.

Immeasurable Outcomes

The harder-to-measure impacts of Cutting Edge are no less important than the ones that can be more easily quantified, and involve shifts in community attitudes, expectations, and recognition in the larger STEM community. The PIs could see these shifts based on individual experiences alone. Tewksbury explained that in the 1990s, if she led a workshop on effective teaching strategies, she was likely to encounter unawareness and skepticism. Midway through Cutting Edge, she found that workshop participants arrived with activities and ideas reflecting knowledge about, and enthusiasm for, the teaching approaches that Cutting Edge emphasized. Instead of convincing an audience that these approaches were important, Tewksbury said, the conversation could start in a different place: “What did you like about [a particular teaching tool]? What’s the hard part? What would you like to figure out how to do better?” It was, as Tewksbury put it, “an entirely different atmosphere.”

This different atmosphere was partly a result of what Macdonald called the “migratory effects” of the program—e.g., connections made at workshops, department-lounge conversations, and Cutting Edge links shared via email. Macdonald and her colleagues were careful to point out that these migratory effects did not happen in a vacuum: Cutting Edge's efforts were complemented and supported by pre-existing organizations like PKAL and NAGT, and joined by newer programs such as the STEM-focused Center for the Integration of Research, Teaching and Learning (CIRTL). Still, there is no doubt the program contributed to a large-scale shift in attitudes.

Another atmospheric shift the PIs noted was that the Earth science education community had become more inclusive: Manduca spoke to witnessing changes in how some workshop attendees thought about two-year college teaching and faculty experiences. Cutting Edge had actively sought to involve members from all types of institutions in order to honor and involve all types of educational and research experiences. Consequently, the program fostered collegial bonds and appreciation.

Beyond the workshop and classroom experiences, Cutting Edge has bolstered practices regarding discipline-specific research and resource-sharing: “I think we are known now as the discipline in which there’s the best connection between disciplinary-based education research and practice,” Manduca said. “We have a mechanism for moving ideas between research and practice.”

Just as Cutting Edge encouraged its participants to work with and improve the solutions to discipline-specific problems, and then feed their work and ideas back into the system, Cutting Edge itself has been working with and improving solutions to STEM-wide problems, and has been feeding its research, wisdom, and vision back into that larger system. STEM-wide organizations like AAAS, NSF, and SENCER have invited talks and workshops from the members of the Cutting Edge team, demonstrating the value of the methods refined and lessons learned over the years of the program. The model of integrating workshops and websites has been applied by other NSF-funded professional development programs on, for instance, teaching computer science, teaching with genomic data, and accelerating systematic change in higher education.

Leadership development was another immeasurable but valuable outcome and has improved the program's reach, strengthened the wider community, and created career opportunities. All four of the initial PIs emphasized the importance of leadership development on all levels, whether it involved graduate students at Career Prep workshops, new workshop leaders, website builders, or the four additional PIs the program gained in its later years (Beane, McConnell, Wiese, and Wysession), whose work was of great value to the program.

Other personal impacts of the program are illuminated through anecdotes and notes of appreciation in the book *500 Notes of Thanks to the National Science Foundation for Supporting 15 Years of On the Cutting Edge*. Faculty around the globe attest to the impacts the program has made on their careers and students. The book contains message after message of appreciation. Alicia Wilson wrote, "I had not known … that workshops and meetings could be engaging and useful." "The Cutting Edge workshops and online materials were so essential in helping me get up and running as a new professor … at a teaching-oriented college," wrote Megan Anderson. "This program has made a huge difference for me, so many of my colleagues, and especially for our students," wrote Leonard Sklar. "My colleagues in other departments are jealous that there is such an organized network for geoscience education," wrote Sarah Titus. "I (and many others) would not be the teachers and scientists we are without this program," wrote Jennifer Wenner. "The workshop was one of the most useful things in organizing my early career," wrote Brad Johnson. "The Cutting Edge effort is the most successful educational endeavor that I am aware of," wrote Darrell Henry. Enrique Gomez Del Campo wrote that Cutting Edge helped him succeed as a minority in the natural sciences; Alejandro Flores credited an Early Career workshop for his success as a grant writer; Kaatje Kraft wrote that Cutting Edge shaped the way she participated in her students' learning. Though these notes of thanks cannot be submitted for formal research, they speak volumes about how the program has shaped and improved career trajectories, research, teaching, funding, and—of course—community belonging.

Passing the Torch

A good way to think about the future of the undergraduate geoscience education community is as a group whose standards have been shifted toward connections, collaboration, and grounding teaching practice in good research. “We taught people how to run good workshops,” Manduca said, “but we also deeply embedded the value of the enterprise, the notions of sharing and inclusion, and the fact that you have to care for [the program, and by extension the wider community] or it won’t last.” Tending to the program, and facilitating the community’s tending of it as well, was an inspiring and demanding task for the four initial PIs, and the additional PIs they brought into the project for the third grant. Now, it is time to let the new programmatic structure, and the already-moving ripple effects of Cutting Edge, continue to shape the future.

As NSF funding approached its close for Cutting Edge, the PIs worked to increase NAGT’s involvement in the program; NAGT was the clear choice for an organization that could help sustain Cutting Edge into the future, and in 2013, Cutting Edge and NAGT entered into a memorandum of understanding. Manduca, as NAGT’s executive director, played an essential role in developing a sustainable management and financial model for NAGT.

In the agreement, NAGT committed to continuing Cutting Edge workshop design principles, website development, and peer review practices. Much of the workshop program was consolidated into the annual Earth Educators’ Rendezvous, though the Early Career workshops would continue to be offered in a separate format. Manduca allowed that, while the consolidation does change the shape of the workshop program, “the Rendezvous continues the focus on an inclusive community that learns together, and it allows for thematic workshops that respond to changing needs within that community.”

Under the guidance of NAGT, the professional development program will continue to evolve: the Traveling Workshop Program (which was not part of Cutting Edge) takes leaders to campuses and regions to support course- and program-level improvements via Cutting Edge workshop design principles. A new, interactive webinar series can be accessed by faculty anywhere in live and recorded formats.

Another memorandum of understanding exists between NAGT and SERC to sustain the Cutting Edge program. Manduca saw the transition as a successful means of sustaining leadership and supporting the infrastructure necessary for high-quality professional development offerings to be integrated with the website.

The demand for Early Career Faculty workshops has meant that some departments are willing to offset the cost for the program. So Early Career workshops will continue to be offered through a combination of registration fees and NSF funding.

That there is a market for this program illustrates the fact that “there was a need and we figured out how to meet it,” as Macdonald put it.

The national survey, too, will continue into the future; the research tool has proved so valuable to the discipline that a team whose members are made up of NAGT- and SERC-affiliated people are finalizing a plan to provide broad access to survey data, as well as a shared management structure for future survey iterations.

Some practical matters involving the health of the program have yet to be solved. Mogk pointed out that maintaining the website involves more than checking for broken links. “To keep the activities fresh, to keep them up to date, is a big challenge,” he said, and went on to explain that “new, good information” needs to be added to the site, or it risks irrelevance through “erosion and attrition.” Manduca added, however, that NAGT currently has a committee dedicated to this problem: exploratory projects are in place, including having community editors for sections of the site (Mogk himself was the first example of such an editor).

To be clear, Mogk has faith in the next generation. “They’re going to have new ideas,” he said, “and we need to respect that. I think we’re in good hands.”

All four PIs agreed that Cutting Edge’s large-scale impact has helped change the landscape of geoscience education. “I think we passed an inflection point. A large-scale shift in teaching methods is gathering momentum,” said Manduca.

“It’s so important to me that we’ve moved the needle,” Tewksbury said. “People who are teaching differently aren’t going to toss [their new methods] out the window and go back to talking at students.” For her, the Early Career and Career Prep workshops contributed something particularly critical to the culture and community: “It’s far easier to catch someone at the start of their career than it is to try to capture people when they’re forty, forty-five, fifty. They’ll have a much longer impact [if they attend a workshop earlier in their career],” she explained.

Manduca’s wish is for the community to continue valuing a culture of sharing. “If they can hold that [culture] together, if they can not fragment, if they can keep it as a big community that has an ethos of floating all boats, and if they can use [Cutting Edge] tools in inclusive ways so that every member of the community is more than they would be without the community,” she said, then the future of undergraduate geoscience education is promising. She also pointed to opportunities to collaborate with the K–12 science community to build an Earth education system that better serves students at all levels.

Macdonald concurred with her colleagues’ hopes and emphasized the importance of inclusivity as the program and the community move forward. She added, too, that diversity, equity, access, and inclusion initiatives would be essential to a healthy future for the discipline, and the individuals who comprise—or could comprise—its community.

With an understanding that could only come from years of experience, and the unexpected twists and turns those years involved, the PIs see that Cutting Edge offers something of lasting value—a community with shared goals and values, but one not defined by a particular curriculum or single set of classroom standards. “We were not a group with a message,” Manduca said, meaning that the program wasn’t based on a doctrine about science and education. Or, to whatever degree there was a doctrine, it was this: *Work with and listen to one another. Share resources. Share what you creative from the resources others shared. Learn from research. Use connections to shape and participate in further research. Value community growth over dogma. Don’t go it alone.*

The next decades will challenge educators in ways that have yet to be understood. Still, Macdonald, Tewksbury, Mogk, and Manduca are optimistic about the ability of the geoscience community to adapt to these challenges. As Manduca put it, “They can use the tools [we developed]. They can use the community and build new tools.”

Then she added, “If that happens, we did a lot.”