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Bringing Mid-Ocean Ridge Discoveries to Audiences Far and Wide

Emerging Trends for the Next Generation

BY LIZ GOEHRING, VÉRONIQUE ROBIGOU, AND KATHERINE ELLINS

Densely packed co-existing aggregations of *Riftia pachyptila* and *Tevnia jerichonana* tubeworms on the 11 m tall Tubeworm Pillar at 9°49.6'N on the East Pacific Rise. White brachyuran crabs actively predate on the red plumes (gas exchange organs) of these tubeworms (note crab with plume in claw at lower center). Image collected from *Alvin* in November 1999. *Courtesy of WHOI, The Stephen Low Company, Rutgers University, R. Lutz (Rutgers), and T. Shank (WHOI)*

ABSTRACT. The "Ridge" community has pioneered not only scientific exploration of and research on the global mid-ocean ridge system but also innovative and attractive ways of reaching out to the public with fascinating stories of scientific discovery and cutting-edge deep-sea technology. This article summarizes 30 years of education and public outreach (EPO) projects conducted by scientists and outreach professionals in the Ridge community to highlight the key principles of effective EPO, such as the importance of targeting specific audiences' needs and expectations. Other elements discussed include collaboration with professionals outside of the scientific community, increased participation of individuals from underrepresented groups in science, and rigorous evaluation to strengthen the impact of future programs. The article also explores how cyber technology and observatory science offer new opportunities for sharing discoveries as they occur and involving the public in the research endeavor. By reaching audiences on a more direct and personal level, these novel approaches may hold the most promise for increasing public appreciation for the marine environment. Scientists' perspectives on EPO programs, lessons, learned, and personal benefits address the question "Why should I do outreach?" Ridge EPO programs highlighted include (1) "Research and Education: Volcanoes, Exploration and Life" (REVEL)—a seagoing, research-focused professional development program for K–12 teachers; (2) "Why is Earth Habitable?"—an iconic American Museum of Natural History exhibit; (3) "Volcanoes of the Deep Sea" and "Aliens of the Deep," two popular IMAX films; (4) "Dive & Discover," an online resource and expedition archive; (5) Extreme 2000, Student Experiments at Sea (SEAS), and From Local to Extreme Environments (FLEXE), three innovative education projects for K–12 students; (6) the Ridge 2000 Distinguished Lecturer Series targeting institutions without marine science programs; and (7) "Beyond the Edge of the Sea," a traveling exhibit of vent-ecosystem illustrations.

INTRODUCTION

The 1977 discovery of life at hydrothermal vents along the mid-ocean ridge spreading center is a wonderful story (Lonsdale, 1977). Aiming to document the presence of actively venting seafloor hydrothermal vents on the Galápagos Rift, geologists in the submersible *Alvin* unexpectedly stumbled upon lush communities of organisms thriving in the toxic brew spewing from the hot springs—giant clams and tubeworms, mounds of mussels, spaghetti worms, microbes—all making up an exotic ecosystem living in the inky darkness, at depths far removed from more familiar life forms. One of the major discoveries of the century, it changed our understanding of the requirements of life on Earth.

To their credit, scientists immediately sought ways to share this story with the rest of the world. Working with National Geographic, they published spectacular seafloor images and reached readers quickly with this amazing oceanographic discovery (Corliss and Ballard, 1977; Ballard and Grassle, 1979). Later, National Geographic, the Public Broadcasting System's (PBS's) NOVA, and the British Broadcasting Corporation (BBC) produced video documentaries for viewing audiences to see footage of billowing black smokers hosting little-known deep-sea communities and to witness research expeditions from their home televisions and VCRs. As mid-ocean ridge discoveries continued, scientists teamed with film producers who used large-format, high-definition IMAX cameras and wove stories of scientific discovery with never-before-seen seafloor footage, creating films that engaged and entertained large theater audiences (Kovacs, 2005; Kusek, 2005). With the advent of the Internet and improved communications from sea, websites were created to chronicle research expeditions, providing first-hand accounts of life and work at sea in near-real time for anyone with a computer to follow (Fornari and Humphris, 2005). Cohorts of K–12 teachers were invited to participate in research expeditions, learning to practice science at sea and sharing their adventures with their students and communities on land (Robigou and Heidenreich, 2003). Even students became involved, phoning scientists who were diving in submersibles, asking questions about the seafloor environment, and submitting proposals for student experiments at vents (Kelsey et al., 2005). In spite of, and because of, their remoteness, mid-ocean ridge ecosystems became known to the world.

The legacy of the Ridge community's 30+ year effort to share the story of mid-ocean ridge science with nonscientists reveals an expansion in outreach goals and approaches that mirrors advances in the field of education and public outreach (EPO). Originally seeking primarily to raise public awareness of the existence of mid-ocean ridges, Ridge EPO evolved to foster a deeper understanding of this unique environment within the larger context of Earth's systems and an appreciation of the importance of science to daily life

BOX 1 | US SCIENCE LITERACY PRINCIPLES

A series of framework documents developed with support from the US National Science Foundation, the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration identify the "big ideas" and fundamental concepts that all Americans should know and understand about Earth (http://www.earthscienceliteracy.org), its climate (http://www.climatescience.gov/Library/Literacy), atmosphere (http://eo.ucar.edu/asl), and ocean (http://oceanliteracy.wp2.coexploration.org). These principles serve to guide education and public engagement.

(Robigou et al., 2005). This evolution parallels advances in the field of Earth systems education (Center for Earth and Space Science Education, 2001) and the growing national emphasis on science literacy reflected in today's National Science Education Standards (NRC, 1996) and benchmarks (AAAS, 1993), current scientific literacy principles (see Box 1) including ocean literacy (Strang et al., 2007), and the new National Research Council report, *A Framework for K–12 Science Education: Practices, Concepts and Core Ideas* (NRC, 2011a). Aided by improvements in technology that allow direct communication with target audiences and facilitate media access, the story of mid-ocean ridge research disseminated farther, reaching more people than ever before. And, as our scientific community experimented with novel ways to showcase its discoveries, EPO approaches involved more personal experiences, providing a connection to the remote seafloor environment and related science on a more direct level. As we are beginning to understand, through the emerging field of Learning Sciences (NRC, 2009), place-based learning (Semken and Freeman, 2008; Williams and Semken, 2011), and current brain research (e.g., Zwaan, 2004), these personal connections can lead to increased learning as people are more likely to care about issues that resonate with their personal experiences.

Liz Goehring *(exg15@psu.edu) is Ridge 2000 Education Outreach Coordinator, Department of Biology, The Pennsylvania State University, University Park, PA, USA.* **Véronique Robigou** *was director of the COSEE-Ocean Learning Communities and REVEL Project, University of Washington, School of Oceanography, Seattle, WA, USA.* **Katherine Ellins** *is Program Manager, Institute for Geophysics, The University of Texas at Austin, Austin, TX, USA.*

Five years ago in *Oceanography*, Kusek et al. (2007) described the changing landscape for mid-ocean ridge EPO, outlining the challenges and opportunities for a better integration of science and education in a technologically dependent world. The authors highlighted policy decisions and events influencing science education and outreach. The question for scientists at the time was not whether to *do* outreach, but rather how to develop the most effective ways to reach out with the goal of developing a well-informed citizenry that could play an active role in maintaining the health of Earth's ocean. While that is still the message today funding agencies increasingly require that education and outreach efforts be evaluated by metrics that go beyond merely cataloging the number of teachers reached or website hits, and instead examine the impact of education and outreach efforts in terms of indicators of understanding and actionable outcomes (NSF, 2009; NASA, 2010; Alpert, 2010). These types of metrics are significantly harder to capture, requiring collaboration with professionals who have experience in this work (e.g., learning sciences researchers, science education evaluators).

This article builds on the 2007 *Oceanography* paper by reviewing the legacy of Ridge EPO efforts and revisiting the challenges and opportunities unique to specific audiences. For each major audience, we describe exemplary Ridge EPO, highlighting some of the best practices of today and lessons learned. The EPO landscape continues to evolve, and today's paradigm is less about finding new venues for outreach than it is about delving deeper to find the best approaches to achieve desired outcomes.

RIDGE EDUCATION AND PUBLIC OUTREACH PROJECTS

One of the first principles for designing a successful outreach project is to identify a target audience and understand its unique needs and expectations. By understanding what motivates members of that audience and how they learn, it is possible to determine reasonable outcomes and develop programs that can help achieve these outcomes (Franks et al., 2006). In keeping with this important first principle, we examine the legacy of Ridge EPO projects for two major groupings: informal and formal science education audiences.

Informal Science Education

Informal science education (ISE) reaches people in nonschool settings and across the life span, from infancy through late adulthood. Learning may occur in designed spaces such as museums, marine science centers, and aquaria; through after-school programs, citizen-scientists programs, and national and international science competitions such as the National Ocean Sciences Bowl and remotely operated vehicle competitions; or in connection with everyday experiences such as participation in science clubs and marine sports, movie attendance, home entertainment, or viewing art exhibits. Because of the diversity in audience ages and backgrounds and the variety of settings in which informal learning occurs (Griffin, 1994), collaboration with partners who know the specific target audience and can tailor and deliver the scientific message to such individuals is critical. These collaborations have major advantages: (1) partners typically bring extensive existing networks that extend the visibility of the project to very large audiences; (2) scientific discoveries are usually placed in a larger context the public understands (e.g., mid-ocean ridge science can be integrated into planetary contexts and concepts that already appeal to the general public); and (3) in the case of designed spaces, studying the educational impact of the exhibit or the educational activity is integral to the mission of the institution.

The Ridge community has been involved in a number of high-visibility efforts in informal settings that succeeded in widespread accessibility to mid-ocean ridge research as well as the stories of deep-sea exploration, underwater technology, and discoveries. Next, we describe examples in three settings: museums, film venues, and art exhibits.

Hydrothermal sulfide structures on exhibit in the American Museum of Natural History (AMNH) Gottesman Hall of Planet Earth, New York City. *Photos courtesy of AMNH*

Museums

Since 1999, two large sulfide chimney samples from the Juan de Fuca Ridge, Northeast Pacific Ocean, have greeted hundreds of thousands of families and students of all ages in the Gottesman Hall of Planet Earth at the American Museum of Natural History (AMNH) in New York City. Designed to help visitors think like scientists, Gottesman Hall is organized around major scientific questions and tells Earth's most significant stories, from its early evolution to the earthquakes and storms we encounter today. The towering sulfide structures in the center of the exhibit serve as icons, posing the question: "Why is Earth habitable?" They invite visitors to ponder the presence of a rich microbial community flourishing on the ocean floor around hydrothermal vents and its role in the origin of life on Earth. The exhibit features interactive activities for visitors to experience the scientist's process of focusing on data as evidence, data-collection techniques, and the use of theoretical models.

In addition to the exhibit's sulfide structures, collected during a joint AMNH and University of Washington research expedition, this scientist-museum collaboration produced the PBS NOVA documentary "Volcanoes of the Deep," an educational website (http://www.amnh.org/nationalcenter/expeditions/blacksmokers), and an exhibit companion book and online course, "Earth: Inside and Out" (AMNH, 2001; Randle and Kinzler, 2005). After 12 years, and hundreds of thousands of visitors, the Gottesman Hall of Planet Earth and its vibrant sulfide installation remain one of the top visited exhibits in the museum (Ro Kinzer, American Museum of Natural History, *pers. comm.*, July 15, 2011).

> The Gottesman Hall of Planet Earth provides experiences that focus on understanding the nature of science. "It is not about doing experiments, but about reasoning based on evidence, making interpretations to assess ideas and drawing inferences. Having the real samples there strengthens that approach. The scientific process is completely interwoven with everything in the Hall and is part of the museum's culture."
>
> *—Ro Kinzler, Senior Director, National Center for Science Literacy, Education and Technology, American Museum of Natural History*

Film Venues

Several successful film projects produced over the last 15 years demonstrate the attraction deep-sea exploration holds for the general public. From PBS's NOVA documentary "Volcanoes of the Deep" and BBC's "Blue Planet–The Deep," to the high-definition IMAX films "Volcanoes of the Deep Sea" and the three-dimensional version "Aliens of the Deep," Ridge scientists have worked with filming experts to create, in each case, a first-of-its-kind, high-impact product. "Volcanoes of the Deep Sea," for instance, was the first to outfit the research submersible *Alvin* with an IMAX camera and 4,500-watt illumination to produce footage that has been viewed by 10 million people in IMAX theaters and by another 150 million TV viewers of all ages since its release in 2003. Through collaborations with masterful storytellers of the entertainment business (Stephen Low and James Cameron), both IMAX films use stunning visuals and immersive stories to capture the imagination of audiences about scientists' work, their lives, and their quests for scientific discovery. Although relatively short-lived experiences, these films leave indelible images in people's minds and hearts, creating a desire for more knowledge of the subject, especially in young audiences. In each of these productions, complementary educational products supplement the film to engage learners beyond the film viewing experience. Distribution of thousands of copies of educators' guides (see http://www.stephenlow.com/educators.html and http://www.walden.com/guide/aliens_of_the_deep), scientists' presentations at film openings, and viewings by special school groups in science centers and commercial theaters serve to extend and broaden the experiences of filmgoers.

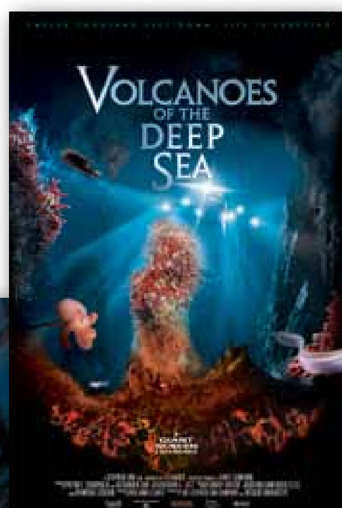
> We believed that the use of this filming technology, combined with Cameron's expertise as a storyteller, would help broad audiences become engaged with the subject matter.
>
> *—Deborah Kovacs, Senior Vice President of Publishing, Walden Media*

Art Exhibits

Many people seek opportunities to learn about and experience the natural world through natural history museums and art galleries. Collaboration with artists offers yet another means to reach audiences, in an aesthetic way that piques curiosity and brings a sense of wonder about the strange creatures and stark landscapes of the deep. The exhibit "Beyond the Edge of the Sea," a collaboration between scientist and artist, features watercolor illustrations of hydrothermal vents that engage these contemplative audiences and take viewers deeper into the intricacies of a painted subject. In the style of John James Audubon's nineteenth century bird illustrations, these seafloor illustrations use exquisite detail rendered through careful observation to reveal the beauty of deep-sea creatures and hostile seafloor environments. To share the collection as widely as possible, the exhibit travels to museums and galleries throughout the country, and a companion education resource guide helps museum staff extend the exhibit's reach to local science and art teachers and their students (http://web.wm.edu/muscarelle/exhibitions/traveling/beyond). This collaborative exploration approach benefits not only audiences but the artist

> The work merges art and science at the moment of discovery.
>
> *—Cindy Lee Van Dover, Professor, Duke University*

BELOW | Dijanna Figueroa, a marine biologist from University of California Santa Barbara, narrates her journeys to the seafloor environments in the large format three-dimensional film "Aliens of the Deep" directed and produced by James Cameron. *Photo courtesy of Walden Media, LLC and Disney Enterprises, Inc.* RIGHT | Poster from the IMAX film "Volcanoes of the Deep Sea" produced by The Stephen Low Company in association with Rutgers University. *Image courtesy of Alex Low and Richard Lutz*



and the scientist as well, bringing fresh perspectives, questions, and excitement to each other's disciplines.

This kind of collaboration has historical consequence. [Artists] have always been part of scientific exploration and, through their work, have brought back discoveries to the public.

—Karen Jacobsen, Artist, In Situ Science Illustration

RIGHT | Entrance display for the *Beyond the Edge of the Sea* traveling exhibit of Karen Jacobsen's scientific illustrations of hydrothermal vent environments. The exhibit was developed in collaboration with Cindy Van Dover and was produced by Muscarelle Museum of Art, The College of William and Mary. *Photo courtesy of Cindy Van Dover*. ABOVE | An exhibit visitor studies the detail in Karen Jacobsen's deep-sea crab illustrations. *Photo courtesy of Heather Nelson, Pennsylvania Space Grant Consortium*

Formal Science Education

In contrast to informal education where learning is self-motivated, self-directed, and addresses life-long learning, formal education typically targets K–16 students and is guided by professionally trained teachers. Its settings include public and private schools, community colleges, four-year colleges, research universities, and even the Web. Since the 1990s, formal science education has been in the midst of significant reform, moving toward teaching and learning that "reflect how science itself is conducted, emphasizing inquiry as a way of achieving knowledge and understanding about the world" (NRC 1996). This reform translates to classrooms with less lecture and memorization of facts and more practice with critical science skills, such as evidence-based reasoning, data collection and analysis, hypothesis testing, and scientific writing. Unfortunately, many science teachers are not experienced in scientific inquiry and, consequently, are not well equipped to guide students undertaking their own scientific investigations. EPO that targets teachers can have a significant "ripple effect" in terms of reaching large numbers of students (Causton and Ivey, 2005), and collaborations between scientists and teachers can help facilitate introduction of inquiry in the classroom (Goehring et al., 2005b). Over the years, the Ridge community has committed a great deal of time and resources to reaching out to teachers and students in formal education settings, with great success.

Reaching Teachers

In 1996, in partial response to science education reform, the NSF-funded Research and Education: Volcanoes, Exploration and Life (REVEL) Project (http://www.ocean.washington.edu/outreach/revel) at the University of Washington was developed to immerse cohorts of K–12 teachers in seagoing expeditions and in the scientific process. The project's participants experienced life on a research vessel, practiced science by conducting research investigations, and chronicled their learning and life on shipboard websites. Working at the elbows of Ridge scientists at sea and in collaboration with them in following years, REVEL teachers became facilitators of genuine, inquiry-based science in their classrooms, and brought the excitement of deep-sea research back to their students. These teachers also became ambassadors for deep-sea research in their professional and local communities, and many turned into sought-after educational leaders, counseling and advising other outreach projects (e.g., IMAX films, Student Experiments At Sea pilot, AMNH distance learning program) and creating new programs and even schools (Kveven and Searle, 2008; Kveven, 2009).

My knees buckled. For the first time in my life as a biology teacher, I held a new as yet unknown species. At that moment, I decided that my students must experience the thrill of discovery.

—Sande Ivey, Biology Teacher, Bangor, PA

Reaching K–12 Students

Other early Ridge outreach targeted students directly. With the advent of the Internet, several in the Ridge community developed expedition websites with an

LEFT | REVEL teachers from Minnesota and Washington check the configuration of the instruments mounted on the remotely operated vehicle (ROV). For each dive, teachers share the ROV operations with their students through daily postings on the expedition website. *Photo © REVEL 2003.* BELOW | Sample page of *Dive and Discover's Vent Biology Infomod* showing a graphical representation of the organisms found at a hydrothermal vent. When the viewer clicks on an organism, text and photographs appear on the right panel to provide more information on that organism. *Image courtesy of Woods Hole Oceanographic Institution*

educational focus that brought "life at sea" directly into the classroom (see list in Kusek et al., 2007). The Woods Hole Oceanographic Institution's award-winning Dive and Discover website (http://www.divediscover.whoi.edu) was, and still is, dedicated to showing viewers the inner workings of a research expedition. The site provides a personal connection to life onboard a research vessel (Fornari and Humphris, 2005) by sharing "eureka" moments of discovery through slideshows, video clips, cruise member biographies, and online "daily journals" that chronicle everything from the day's dive plan and specialized technology used to the ship's dining menu. One of its most innovative features, Dive and Discover's interactive "InfoMods" help students explore various topics in depth, and are referenced extensively by other educational programs. In a similar manner, the Extreme 2000–2008 website series from the University of Delaware (http://www.ceoe.udel.edu/deepsea) shares the excitement of deep-sea exploration through cruise logs, image galleries of seafloor geology and technology, and lifelike animations of seafloor creatures, along with a professionally produced companion video.

The Extreme series also successfully experimented with new ways to involve students in the research expedition through Virtual Science Fairs, an *Alvin* simulator, and its signature "Phone Call to the Deep" in which 15 classrooms around the world were patched in to a call to the seafloor while additional classrooms listened in. Student and teacher feedback consistently rated the phone call as one of the most rewarding parts of the program, likely because of the personal connection created with the remote environment and the scientists and *Alvin* pilots working there. A surprising but important side effect of these expedition websites has been the impact they have on the scientists and crew who, through communication with participating school children, are able to see with fresh eyes the tremendous excitement and awe inherent in their work.

Given the successes of early Ridge outreach projects, the Ridge 2000 Program Office invited a group of experienced educators and science education evaluators to examine successful outreach projects and determine what new approaches were needed to reach a larger audience. This group convened in 2002 and suggested that giving teachers and students access to scientists and their research, authentic data, and a dynamic, remote environment were all highly motivating factors (Goehring et al., 2005b). Research on student learning confirms that "students learn science by actively engaging in the practices of science, including conducting investigations, sharing ideas with peers, and [engaging in] specialized ways of talking and writing" (NRC, 2000, 2007). The NSF-funded Ridge 2000 Student Experiments at Sea (SEAS) pilot was designed to actively facilitate student participation in deep-sea science. Patterned after the US National Aeronautics and Space Administration (NASA) education offerings in which student experiments are conducted in space, SEAS provided a formal venue for students to become involved with seafloor research, including a written proposal competition, an at-sea experiment journal where data from selected experiments were posted for student access, and a scientist-judged report fair, all delivered via the Web (http://www.ridge2000.org/SEAS/2003_04/

The phone call to the scientists was really cool. I can't believe that we were actually having a conversation with someone who was underneath the sea in a submarine. I will probably remember that forever.

—Student Participant, Extreme 2008

experiments.php). Nine student experiments, ranging from determining deep-sea crab feeding preferences to exploring the oxidation of metals in the presence of vent fluid, were conducted over the three-year pilot. Feedback from teachers indicated that participation in this type of authentic science led to a paradigm shift in students' understanding of science, from naïve thinking that data will align with the "right answer" to realizing that data are "messy" and must be interpreted to reveal trends that often lead to more questions (Goehring et al., 2005a). The SEAS pilot also tested the approach of a community-wide outreach project in which multiple Ridge researchers could contribute to an independently funded EPO project, serving as proposal reviewers, cruise hosts, science advisors, or report fair judges (Goehring and Williams, 2006).

Building on the successes of SEAS and lessons learned from this and other Ridge EPO, the Ridge 2000 Office collaborated with learning sciences researchers at The Pennsylvania State University and the Global Learning and Observations to Benefit the Environment (GLOBE) science and education network to develop the NSF-funded From Local to Extreme Environments (FLEXE) project (http://www.flexe.psu.edu). FLEXE is a Web-based science education program that features the mid-ocean ridge environment and interdisciplinary research to motivate students to learn about Earth systems science. In FLEXE, students focus on understanding data both collected locally and provided by scientists working in extreme environments. FLEXE teaches students about the collaborative nature of science by engaging them in exchanges with other students (e.g., interpreting each other's locally collected data, anonymous peer review of written reports) and with deep-sea scientists through the facilitated FLEXE Forum. Rigorous educational research is a primary goal of the project, particularly research examining the impact of the project's various components on student learning as well as on student attitudes toward science (Kerlin et al., 2009, 2010, and recent work using argumentation analysis to compare domestic and international class partnerships). Current evaluation is focusing on whether there is a significant increase in student engagement and learning if scientists participate in "live" FLEXE Forums as opposed to students using archived versions of these forums. Recent reports confirm the need for this type of experiential learning in successful science, technology, engineering, and mathematics (STEM) education, along with the requirement for rigorous evaluation to understand best practices (NRC, 2011b).[1]

SEAS brought the fun and excitement of deep-sea research into my classroom and school community. I was proud and excited as I listened to students share their SEAS experience with our school community and visiting school board members at our yearly Night of Excellence. The biggest thrill of all, however, was when one-third of the class claimed they wanted to be marine scientists when they grew up, a decision initiated and nurtured by the Ridge 2000 community and the SEAS Project!

—Mellie Lewis, Science Teacher, Columbia, MD

This [FLEXE Forum] activity was great. I loved it! It gave real data, which is hard to come by for everyday teachers. I plan on using this activity forever in my classes.

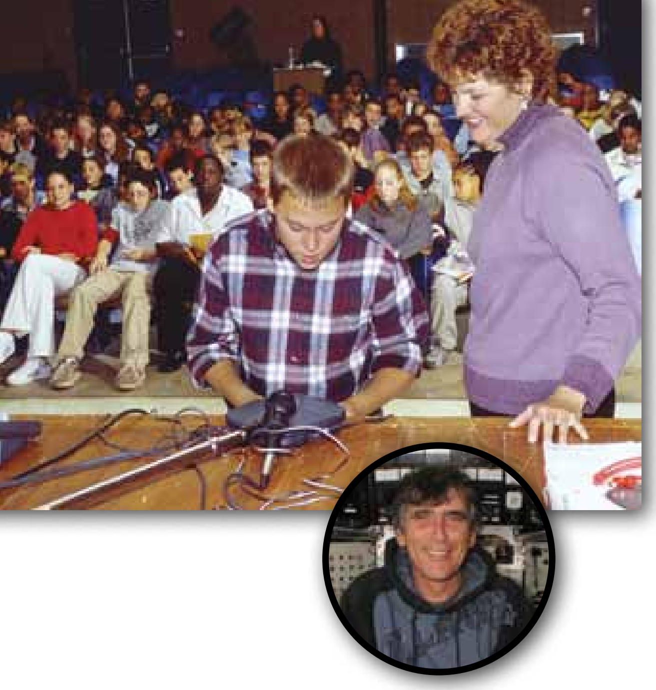
—Pilot Teacher, FLEXE

Reaching Undergraduates

Recognizing the power first-hand experiences and personal stories have in gaining students' attention and interest in a subject matter, many Ridge scientists use examples from their own research to engage students in their courses. And many provide undergraduates with research opportunities and work in the field on research cruises. Certainly,

[1] Because of its alignment with recommendations made in the National Research Council report outlining elements that contribute to successful STEM education, the FLEXE project was invited to participate in a conference announcing the release of the report (http://successfulstemeducation.org/content/agenda).

Middle school students in Massachusetts analyze a seafloor photomosaic for patterns in mussel distribution. The activity is part of the Student Experiments At Sea (SEAS) curriculum designed to prepare students to develop ideas for experiments at sea. These students submitted a proposal to examine crab feeding preferences at vent environments. *Photo courtesy of Carolyn Sheild, Lexington, MA*



As part of the University of Delaware's award-winning Extreme series of online expeditions, students from Talley Middle School in Wilmington, Delaware, participate in a "Phone Call to the Deep" with Craig Cary (inset) as he explores hydrothermal vents in the submersible *Alvin*. Cary and his colleagues answered questions from classrooms across the United States and internationally about the bizarre life that thrives in extreme environments and the mysteries that scientists are uncovering. *Photos courtesy of the University of Delaware*

these injections of real-life examples in course content facilitate a more personal connection for students with the subject, and field research experiences early in their schooling often serve to entrain future scientists (Macdonald, in press). In an effort to reach students at institutions without ocean sciences programs, Ridge 2000 has offered a Distinguished Lecturer Series (DLS) to colleges and universities throughout the United States since 2004. Lectures target undergraduate and graduate-level audiences with the aim to share cutting-edge Ridge research with audiences not familiar with this work, and ultimately to attract students into ocean sciences. To date, the DLS has featured 31 Ridge scientists from multiple disciplines at over 108 institutions and has received very positive feedback. In recent years, the DLS has also focused on minority-serving institutions, selecting two or three of these host institutions each year to expand exposure of under-represented groups to marine studies.

> I haven't heard that sort of enthusiasm from students for a science seminar speaker in many years.
>
> *—Dawn J. Anderson, Berea College, KY (about a talk by Peter Girguis, Harvard University, Distinguished Lecturer, 2006)*

> DLS was also a great opportunity for me to meet with students and faculty at universities that don't focus on marine research, to discuss what it's like to work at sea, the tools we use, and how marine geology does and doesn't differ from terrestrial geology.
>
> *—Kenneth Rubin, University of Hawaii, Distinguished Lecturer, 2011*

Capitalizing on the connections colleges and universities have with their local communities, distinguished lecturers also present public lectures during their visits, arranged by the host institutions and often given at local science centers, aquaria, or museums. This public presentation benefits both parties, providing additional venues for lectures at no additional cost to the program, and providing host institutions the opportunity to offer dynamic research presentations to their constituents, including high school students, teachers, and other members of the local community.

IMPORTANT ELEMENTS FOR FUTURE EPO

Ridge EPO efforts have proliferated and matured over the years. What started as a new field where early projects stood out in the relatively sparse EPO landscape has grown into a lush and crowded field with projects competing for limited resources. Out of this landscape, three important elements emerge for EPO projects to succeed in the future.

Collaboration is Key

Collaboration with Experts for Knowledge Translation

Common to each of the successful Ridge outreach projects is a partnership between Ridge scientists and experts outside of their research community, either with informal science education professionals, such as museum professionals or filmmakers, or with education professionals such as master teachers, curriculum developers, or educational networks. In each case, the partner brings expertise in translating science for target audiences. They have in-depth knowledge of audiences' needs and expectations, as well as experience working through the barriers continually challenging these audiences. What they lack is cutting-edge scientific expertise and access to newly discovered environments, both motivating elements for their settings. Informal science education professionals rely on the knowledge, vision, and firsthand experience of scientists to develop authentic, state-of-the-art products (Helling and Solomon, 2005; Alpert, 2010). STEM educators and curriculum developers turn to scientists and science organizations to stay abreast of scientific advances, keep science education current and relevant for students, and provide opportunities to involve students in authentic science experiences.

Collaboration with Other Programs and Networks for Dissemination

Strategic partnerships with science teacher and education networks, including the National Association of Geoscience Teachers (NAGT), the National Science Teachers Association (NSTA), and the Centers for Ocean Science Education Excellence (COSEE), can broadly disseminate Ridge EPO (Kinsley and Robigou, 2007). As shown by the Ridge 2000/GLOBE collaboration through FLEXE, GLOBE educators and students worldwide have access to mid-ocean ridge research and discoveries. In addition, Ridge researchers can partner with related research programs such as the Ocean Observatories Initiative (OOI), Geodynamic Processes at Rifting and Subducting Margins (GeoPRISMS), EarthScope, and the Integrated Ocean Drilling Program (IODP) to infuse relevant Ridge science into the outreach efforts of these ongoing programs.

Research and Evaluation Are Required

As the EPO field matures, funding agencies are increasingly looking for evidence that outreach programs are achieving their desired outcomes (NSF, 2009; NASA, 2010). However, in addition to monitoring program metrics and indicators to gauge a program's effectiveness, there is a growing recognition of the need for research to understand factors facilitating learning (NRC, 2009). Knowledge of what leads to learning in informal settings comes from rigorous evaluation of focus groups and target audiences, along with subsequent publication of the results to instruct the field (NRC, 1999; Falk and Dierking, 2000). Similarly, determining success in the K–12 setting ultimately involves evaluating student learning and attitudes toward science as a function of the educational offering; however, many outside factors also affect these outcomes, such as students' prior preparation, teachers' approaches and effectiveness, classroom time, and school setting (NRC, 2007). Controlling for these variables is difficult, requiring innovative approaches adapted to each specific case to obtain valid results (Carlsen et al., 2011). In both formal and informal settings, evaluation also involves meeting the requirements of human-subject research defined by an Institutional Review Board (IRB). Working with experienced evaluation professionals and learning research scientists is now imperative.

Broaden Diversity

The most rapidly growing segments of the US population are largely underrepresented in science and engineering (National Academies, 2010) and, as a result, the scientific community is missing tremendous potential. The situation is particularly acute in the geosciences, where fewer bachelor's and master's degrees are awarded to minorities than all other science and engineering fields; only 4% of geoscience doctoral degrees are earned by minorities (National Academies, 2010). Attracting and retaining minorities is a priority for the key scientific agencies (NSF, 2007a,b, 2009; NASA, 2010) and, therefore, must be incorporated into geosciences educational efforts. Rather than taking this challenge on single-handedly, Ridge investigators can collaborate with experts and networks already addressing the unique needs of underrepresented groups (Huntoon and Lane, 2007). In 2009, for example, the Ridge 2000 Program Office teamed up with an NSF Opportunities for Enhancing Diversity in the Geosciences project, the TeXas Earth and Space Science (TXESS) Revolution, to feature Ridge 2000 curricula and distinguished speakers at a professional development academy for minority-serving teachers (Ellins et al., 2010).

FUTURE DIRECTIONS

Cyber Technology Is Redefining Education and Outreach

Advances in cyber technology are having a significant impact on education and on how to reach public audiences. As previously described, early Ridge expedition websites set trends, engaging the public by enabling direct communication with scientists at sea. Ridge K–12 education initiatives took the approach further by facilitating cyber learning through student-scientist interactions such as Ask-A-Scientist forums and data-driven learning activities (Govenar, 2005; Kerlin et al., 2010). Ridge scientists have also engaged K–16 audiences through live webinars that use novel online concept-mapping software to help communicate key ideas (see Peter Girguis's hydrothermal vent webinar and blog at http://cosee.umaine.edu/coseeos/webinars/rolemodel/0810webinar.htm). At the undergraduate and graduate levels, Virtual Ocean (http://www.virtualocean.org), a new platform that integrates the GeoMapApp tools with the NASA World Wind 3-D Earth browser, enables advanced visualization of and research on the seafloor environment by tapping into extensive databases of bathymetric maps and data sets.

For public audiences, Ridge scientists are capitalizing on the availability of online resources such as the Encyclopedia of Life (EOL; http://www.eol.org) to share their findings through the Web (e.g., see Colleen Cavanaugh's EOL podcast on tubeworm symbiosis at http://education.eol.org/podcast/riftia). As smart phones and tablets proliferate, there are countless opportunities for developing applications that feature Ridge science. Two examples are the new GeoMapApp for the iPad (see http://www.geomapapp.org) and the recently launched GoogleOcean tour of important Ridge 2000 sites (http://www.google.com/earth/explore/showcase/ocean.html#columbia-hydrothermal). Some researchers are exploring the use of serious games, an emergent field that uses gaming as a mechanism for producing electronic experiences, with problem solving and learning goals, to engage audiences. Currently, a pilot initiative from COSEE California and the Birch Aquarium at Scripps Institution of Oceanography is using video game technology in an informal science setting to provide visitors a "virtual" experience of exploring hydrothermal vents (see Deep-Sea Extreme Environment Pilot [D.E.E.P.] trailer at http://www.youtube.com/watch?v=sNpCM-FpeDQ). The investigators are interested in understanding the impact of game-based exhibits on visitors' learning in the aquarium. Each of these examples using new cyber-based technologies is enabling the dissemination of Ridge discoveries far beyond traditional reach and into the virtual space that the younger generations inhabit.

> The most far-reaching effect may be a significant shift in public attitudes toward the ocean and the scientific process.
>
> *—John Delaney, Director of Interactive Oceans Program, University of Washington*

It is potentially more significant that new technologies advancing the way deep-sea research is conducted (e.g., telepresence-enabled ocean exploration, ocean observatories) are simultaneously creating new ways to share discoveries with the public. The US National Oceanic and Atmospheric Administration's new high-tech ship *Okeanos Explorer,* with its enhanced high-speed communications and telepresence capabilities, will soon connect to interactive museum exhibits at the Exploratorium in San Francisco and take the public on sea-going journeys while their feet stay firmly planted on land (Kerr, 2009). The University of Washington's Interactive Oceans project (http://www.ooi.washington.edu) currently "teleconnects" with college students across the country, using tweets and live broadcasts from sea and the seafloor to give Web audiences ringside seats to their at-sea work. With the growing popularity of electronic tablets, cellular phones, and social networking, the public will be able to plug into deep-sea environments in real time, from anywhere. As seafloor observatories evolve, unprecedented levels of optical communication bandwidth and electrical power will open the flow of imagery and information to the public in ways still unimaginable. This virtual "human presence" in the ocean will enable real-time exploration of previously unreachable parts of our natural world and modify the way stakeholders interact with and in this remote environment. It is hoped that this will cause a profound shift in public attitude toward and appreciation for the ocean and science. Researchers in the learning sciences are eager to work with pioneering research communities like Ridge to understand how use of new media in these ways affects learning (NRC, 2009).

The Scientist's Perspective: Outreach Is Rewarding

In preparing this paper on the legacy of Ridge EPO, we had the opportunity to interview many of the researchers involved with successful EPO projects; in the process, we discovered a surprising but also affirming trend—that the most engaging and effective projects tended to be fueled by scientists' passion for sharing their research with others. Certainly, given the flood of demands on scientists' time (e.g., mounds of data to be analyzed and interpreted, research cruises to conduct, students to advise, papers and proposals to write, academic and community obligations to meet), they can ask: "Why should we *also* get involved in outreach?" Responding to funding agencies' requirements to address the broader impacts of their research work is certainly an incentive, but successful EPO efforts are usually motivated by something more.

Many scientists, themselves awed and inspired by ocean floor processes, are eager to tell their stories of exploration and adventure to as many others as

> With an IMAX film, a scientist can give back to the public—to millions of people. It is an obligation for the scientist and, in a way, pay back time for being able to do what he/she loves doing, funded through public funds.
>
> *—Richard Lutz, Professor, Rutgers University*

> Those little voices, coming through the phone, helped us see that what we were doing was actually really cool! You can lose sight of that. We realized just how fortunate we were to do this science.
>
> *—Craig Cary, Director of Extreme 2000, University of Delaware*

possible. Some, recognizing the privilege of being able to pursue their intellectual passions with public resources, see EPO as a way to give back by sharing the discoveries and knowledge that ensues from the research. And, like a positive feedback loop, the excitement generated is itself rewarding. Piquing the public's curiosity with stunning movies and real-time videos of the vent environment is fun. Watching a science teacher invited to sea experience a "eureka" moment about scientific discovery, or hearing a faraway child tell a researcher how "cool" his/her work is validates the scientist's own excitement for discovery. Seeing casual viewers mesmerized by a painting of the exquisite intricacies of a "yeti crab" reminds both the scientist and artist of the astounding nature of deep-sea work.

CONCLUSION

As the NSF-funded Ridge 2000 Program closes and an era of ocean-observing technologies drives the research forward, Ridge scientists will undoubtedly continue to tell their scientific stories to the public. Major and pressing challenges lie ahead for the next decade, but the Ridge community is well positioned to continue to contribute in even more significant ways. As the research community broadens participation in the research, more diverse scientists will tell their remarkable science stories about mid-ocean ridges in novel ways. Nascent ocean-observing networks, with their adaptive robot sensors and real-time, interactive capabilities, will open the doors to researchers, educators, learners, and anyone else, holding the potential to redefine how we all explore, learn, and ultimately interact with the deep-sea environment. And, by collaborating with researchers in the field of learning sciences, we will ensure that education in all its forms (from formal instruction to social networking) benefits from a better understanding of how people learn and make decisions in a technology-driven world.

It is human nature to explore and build familiarity with our environment through interaction. Personal experiences and stories allow us to share this familiarity with others (Wilson, 2002). The advent of ocean observatories holds the promise to bring the ocean to our fingertips, and this might be the best future avenue for encouraging as many citizens as possible to appreciate and care for the ocean and Earth.

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