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Transforming Undergraduate Research Opportunities Using Telepresence

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ABSTRACT

The National Science Foundation funded the *Transforming Remotely Conducted Research through Ethnography, Education, and Rapidly Evolving Technologies* (TREET) project to explore ways to utilize advances in technology and thus to provide opportunities for scientists and undergraduate students to engage in deep sea research. The educational goals were to engage students in research in which they develop a hypothesis and research plan, experience a distant environment, collect data remotely, and interact with the scientific community. Eight undergraduate students from three universities participated, working closely with a professor at their institution with additional mentoring by other scientists. This paper describes the educational portion of TREET, students' experiences conducting ocean science research using telepresence, and lessons learned about the promise and challenges of using telepresence to engage undergraduate students in research. The TREET project consisted of three phases: Phase I, a seminar and the development of a research plan; Phase II, a telepresence-enabled cruise; and Phase III, a postcruise seminar and data analysis. An evaluation of the program shows that students conducted their own research and experienced real-world scientific challenges associated with working at ocean depths from shore. While the experience was valuable for students, there were several lessons learned that have implications for future implementations of telepresence-enabled programs, including the importance of scheduling research experiences for undergraduate students, providing support for data analysis, building community, and developing clear communication strategies from the remote site. The TREET project represents a promising step in imagining the future in which telepresence can open more opportunities for undergraduates. © *2016 National Association of Geoscience Teachers*. [DOI: 10.5408/15-118.1]

Key words: research experiences for undergraduates, telepresence, field experience, ocean science

INTRODUCTION

During authentic undergraduate research experiences, students collaborate with faculty on research projects and have the opportunity to learn about a specific area of study as well as the research process in general. Through these experiences students play a significant role in all phases of research from performing the tasks of a technician to designing research, placing it in the context of scholarly literature, and presenting work orally or in written format (Bauer and Bennett, 2003). Undergraduate research is increasingly valued as a critical component of science education (Halstead, 1997; Hensel, 2012) because authentic research experiences have been shown to help students develop a number of research skills and knowledge—among them the ability to do science, develop independent thought, and communicate ideas (Kardash, 2000; Seymour et al., 2004; Hopper et al., 2013). Undergraduate research opportunities have also been correlated with high student engagement, retention, and advanced learning (Nagda et al., 1998; Russell et al., 2007). Gains in students' intellectual development have been reported by both students and faculty (Hunter et al., 2007). Students themselves perceive that their skills have improved significantly (Bauer and Bennett, 2003) compared to those not participating in research experiences for undergraduates (REU) programs. Moreover, students conducting research report a sense of ownership of the results and a sense of the real struggle scientists face (Kinkead, 2003; Seymour et al., 2004).

In addition to participating in research experiences on campus, many geoscience undergraduate students engage in field-based experiences ranging from local trips to extended courses (Knapp et al., 2006; Elkins and Elkins, 2007). Fieldwork provides an opportunity for learning that cannot be duplicated in a class or lab setting, significantly enhances students' understanding of content, and increases their engagement and interest in the field (Fuller et al., 2006; Stokes and Boyle, 2009). Practices that are paramount for fieldwork, including asking questions and making and communicating observations, are important to the formative training of geoscientists (Niemitz and Potter, 1991; Carlson, 1999; Rowland, 2000). According to Kent, Gilbertson, and Hunt (1997), "From the student viewpoint, all field activities can be placed somewhere on two continua: first, between observation and participation; second, between dependency and autonomy" (p. 315). Through immersive technology Bruce et al. (2014) are exploring the effectiveness of virtual geologic field activities on learning, which enables students to experience remote and physically challenging regions. Such guided exploration promises to open up remote field regions that are otherwise inaccessible.

The great potential of telepresence (a set of technologies, often including video and audio, that allows a person to feel present at a place other than their true location) lies in its ability to enable a human to experience and function in a distant environment, as if he or she were physically present in that location. Telepresence has provided rich visual experiences of ocean environments through live streaming

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TABLE I. Summary of scientists participating in the TREET project.

Scientist	Institution	Location	Student Mentor
Q	Harvard University	Shore	X
R	Duke University	Shore	
S	Woods Hole Oceanographic Institution	Shore/Ship	
T	Woods Hole Oceanographic Institution	Ship	
U	University of Rhode Island	Shore	
V	University of Idaho	Shore	X
W	University of Rhode Island	Ship	
X	Michigan State University	Shore	X
Y	University of Rhode Island	Ship	
Z	Woods Hole Oceanographic Institution	Shore	

video. More recently, ocean scientists have been exploring ways to conduct telepresence-enabled deep-sea research (Brothers et al., 2013; Wagner et al., 2013) and to connect landlocked scientists with colleagues at sea (Kintisch, 2013).

Dr. Robert Ballard pioneered the use of telepresence for ocean science education as a way to provide students a "you are there" experience (Feldman and Viola, n.d.), in which they could observe firsthand scientific discoveries at the seafloor. The first telepresence-enabled educational expedition took place in 1989. As telepresence technology has become more widely available, educators have been exploring ways to move from a passive "being there" approach to a broader use where "psychological presence" means that students are actively engaged in the learning (Fowler and Mayes, 1997). A telepresence field experience was conducted in 2012, pushing the boundaries of what it meant to engage researchers and student teams in supporting an ocean exploration mission when the participants were on shore. In that experience, students were initially an audience observing the science missions, but that changed and scientist–student teams on shore provided key data analysis that was used to inform planning decisions (Van Dover et al., 2012). This paper describes a National Science Foundation-funded project designed to explore further the engagement of a group of undergraduate students and their professors in conducting their own deep-sea science research by remote access.

PROGRAM DESCRIPTION AND IMPLEMENTATION

The Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) program of the National Science Foundation (NSF) funded the *Transforming Remotely Conducted Research through Ethnography, Education, and Rapidly Evolving Technologies* (TREET) project to explore ways to utilize advances in technology, including remotely operated underwater vehicles (ROVs) and telepresence, to provide opportunities for scientists and undergraduate students to engage in their own deep-sea research and transform the way oceanographic research and education is done. The project was comprised of an oceanographic research program within an ethnographic and educational research study designed to investigate transformative ways to conduct research remotely, provide students with active participation in research as it is conducted at a remote location, and discern how to make better use of telepresence for education in the future.

Ocean Science Research

The goals of the ocean science research were initially focused on the impact caused by the release of the greenhouse gases methane and carbon dioxide from the seafloor near the Kick 'em Jenny underwater volcano off the coast of Grenada and the Barbados mud volcano cold seeps off the coast of Trinidad. The research set out to explore the geological processes that underpin the hydrothermal and cold seep systems, quantify the gas composition, and study the biological communities and how they may be coupled with the systems (Bell et al., 2015). Over the planning and implementation of the project, the research objectives were refined to investigate the composition, rate, and distribution of fluid and bubble flow at cold seeps; changes in gas flux; the distribution of cold seeps; and mass-wasting processes around the Kick 'em Jenny volcano; and to explore how technology can be used to improve the study of deep-sea biogeochemistry. Ten scientists participated in the research cruise, with three scientists on board the ship and seven conducting their research from shore (Table I). All the scientists were conducting their own research while some were also mentoring the undergraduate students.

Ethnography Research

The goals of the ethnographic research were to analyze social interactions, information flow, and access to and analysis of scientific data brought about through the use of remote telepresence. Scientists who had not previously used remote telepresence methods are now interested in developing the use of such tools both for their own research and for the long-term sustainability of their fields by attracting and retaining the next generation of researchers. The ethnography research, therefore, focused on providing insight into the work practices of this project and how the findings might impact the larger context for the field.

Educational Research

The educational portion of TREET engaged a small group of undergraduate students in research activities for a year and half with extensive mentoring. Although this project was not funded by the Research Experiences for

TABLE II. Summary demographics of student participants.

Institution	
Harvard University	2
University of Idaho	2
Michigan State University	4
Gender	
Female	5
Male	3
Year	
Senior	1
Junior	6
Sophomore	1
Major	
Geology and Geological Sciences	5
Anthropology	1
Biology	1
Geology and Physics	1

Undergraduates (REU) program at NSF, the education portion was similar to that of the REU program in that students conducted specific research projects, working closely with faculty and other researchers, and student expenses were covered by the project. The goal was to provide a unique opportunity for students to engage in their own deep-sea research project through the use of telepresence to collect data via ROVs.

Research conducted by scientists and the ethnographer was integral to the overall project, and reports about these research efforts have been published independently (e.g., Bell et al., 2015). This paper focuses specifically on describing and evaluating the educational component of the TREET project.

THE TREET EDUCATIONAL PROGRAM

The design of the educational program was informed by prior research indicating that (1) the level of involvement by students correlates with the degree to which they were immersed in the culture of science (Campbell, 2002; Russell et al., 2007), (2) REU experiences sustained over multiple semesters tend to demonstrate stronger outcomes (Sadler et al., 2010), and (3) the quality of faculty mentoring is important (Russell et al., 2007). The TREET program intended to incorporate these lessons by engaging students in a long-term research project, during which students would work with their professors and other research scientists to help them define valid research questions, develop research plans, and collect and analyze data.

Participants

The scientists who were recruited by the principal investigator (PI) of TREET specifically for the project had each conducted ocean science research and had shown interest in conducting research remotely. These scientists understood that they would send equipment and tools to be deployed by those onboard the ship and then guide the data collection from shore. Additionally, they needed to be willing to offer research opportunities for undergraduate students across multiple semesters and be responsible for supporting student engagement throughout the project. Three early career scientists (also referred to as professors and mentors in this paper) from the University of Idaho, Michigan State University, and Harvard University participated in the project. They recruited eight students during the fall of 2013. Students agreed to enroll in two semester-long, credit-bearing independent studies, each of which included participation in face-to-face meetings with their professors and a seminar offered by the TREET project, which was delivered by the PIs and participating scientists. The scientists attempted to recruit students with an aptitude for science, interest in doing research, and willingness to commit to the project over multiple semesters. Recruitment methods varied from (1) an application, (2) a flyer recruiting upper-level students in a geology department, and (3) an email to the participating scientist's classes describing the opportunity. Students were selected based on prior knowledge of students' maturity, intellectual curiosity, and enthusiasm. Students were sophomores, juniors, and seniors (Table II).

Three Phases of TREET

The TREET project consisted of three phases: Phase I, a seminar and the development of a research plan; Phase II, a telepresence-enabled research cruise; and Phase III, a postcruise seminar and data analysis. Phase I began in the spring of 2014. To prepare for the cruise, students participated in an online seminar. The seminar, which included a syllabus with weekly readings and discussions, was designed to introduce the students to the project goals, provide scientific background about the research sites, and review the tools and the advanced robotics available on the ship. The 12-week seminar included a 2-week overview of the TREET project and a brief exploration of the research opportunities, 5 weeks introducing the participating scientists' areas of interest and goals for the cruise, 3 weeks of student presentations of their research goals, and 2 weeks creating and finalizing an overall research plan for the cruise. The seminar included both synchronous teleconference meetings—in which everyone could be "present" by video and audio from remote destinations—and a password-protected asynchronous blog.

In parallel with the seminar, students met at their respective institutions with their mentoring professors to define each student's research questions and develop their plans. The majority of student work—discussions about the content presented in the seminar, learning about the tools that were available on the ROV, and planning the research projects—took place during these meetings. The number of meetings with individual professors varied widely. At one school students met face-to-face just a few times during the spring semester with their professor while other groups met weekly.

In late September, 2014, the Exploration Vessel (E/V) *Nautilus* with the ROV *Hercules* set sail to begin data collection and exploration at two research sites in the Caribbean. The cruise lasted three weeks. On board the ship were the ROV pilots, engineers, scientists, graduate students, and the crew. At the same time, 7 of the 10 TREET scientists and 7 of the 8 undergraduate students (one student dropped out of the project prior to the cruise) arrived at the

FIGURE 1: Students and scientists working at the ISC. (Photo courtesy of Zara Mirmalek)

University of Rhode Island's Inner Space Center (ISC), where they were trained by the ISC staff on the communication and video telepresence technology for guiding the research. The ISC is equipped with multiple large monitors and audiovisual equipment designed to provide technical support for research expeditions. Scientists and students at the remote ISC site were able to guide the fieldwork nearly 2,000 miles away. Scientists on board the ship were also conducting research and guided the data collection for their work from the ship.

While the cruise was under way, teams of people worked together on ship and on shore around the clock. On the ship, constant rotation of watch standers on 4-h shifts included four people (engineer, scientists, and ship staff) in the onboard command center. On shore, there were watch standers at the ISC, including a chief scientist, a research scientist, and one or two undergraduate students on 6-h shifts; they worked with personnel in the ship command center to direct the ship, the ROV, and the data and video collection. All work was coordinated between ship and shore groups through satellite video feeds, radio communication technology, and nightly phone calls. Participants on watch in each location closely attended to the live video feed from the ROV, developed and refined mapping and data collection plans, and recorded observations in a science chat area accessible by all authorized on the cruise.

During the first few days of the cruise, students participated mainly by recording observations in the science chat log; they used the radio communication to talk with those on board the *Nautilus*, and occasionally answered questions emailed to the ship communicator from the public, who were also able to observe the cruise video feed on a website. As ROV dives moved to site locations to collect student data, students occupied the watch leader's chair and helped direct the data collection while the scientist responsible for mentoring the student sat next to the student to offer support and advice (Fig. 1).

Following the cruise, which ended in early October, each student returned to their institutions with the goal of analyzing the data collected on the cruise. The shore-based team of scientists and students met once prior to leaving the ISC to discuss the data needs of each participant, to clarify how the data would be made available, and to identify key personnel related to postprocessing certain data. Taking advantage of the fact that research projects developed by the students often relied on expertise beyond that of their professors, teleconferencing meetings were set up to supplement students working face-to-face with their professor at their home institutions.

Data were distributed in batches. The first batch was navigation data, multibeam sonar data, and event and science chat logs. The second batch included a disc of video from *Hercules* that required little processing. The third batch

TABLE III. Student research questions, data, and analysis.

Student	Phase I: Goal	Phase II: Data Collected	Phase III: Analysis
A	How do the composition, rate, and distribution of fluid flows at the Barbados mud seeps vary?	Fluid flow: none; bubble video imaging at few sites	Did not find fluid flow and bubble flow analysis was inconclusive
B	Does bathymetry show changes between this year and last year?	Collected bathymetry data	Analyzed bathymetric data
C	What is the spatial distribution of geologic features in and around the Kick 'em Jenny volcano?	Collected photomosaic	Characterized surface features by color and textures to show spatial distribution of features
D	How does biodiversity vary at cold seeps from site to site?	Collected photomosaic and bathymetry maps	(Presented the status of work completed, but did not complete analysis)
E	Characterize hydrothermal circulation around Kick 'em Jenny saddle.	Photomosaic, subbottom profiles; laser line scan data	Analyzed photomosaic and began subbottom data analysis, compared bacterial mats as a proxy to show differences in circulation
F	What are the different lithology and facies that make up the debris avalanche?	Video of debris avalanche, photomosaic, vertical transect of avalanche	Created georeferenced photos on map of area and located carbonate outcrop, volcanic contact area, and columnar jointing

was data that required time-intensive postprocessing by specific individuals and labs (e.g., creation of photomosaics). Students worked with the help of their professors as well as support from the larger TREET scientific community to analyze their data. In the spring of 2015, six of the students (the seventh student did not continue for a third semester) and all of the participating scientists presented the analysis they had completed to date and described what they had learned, roadblocks they encountered, and potential future analysis.

EVALUATION OF PROGRAM

This paper describes the educational portion of the project and evaluates the viability of using telepresence to engage undergraduate students in conducting research. Our hypothesis was that students could participate in research activities from planning to fieldwork and data analysis through the use of telepresence technologies. In doing so, students would benefit from an authentic research experience, including being involved in real-world science, participating in fieldwork (a deep-sea cruise) from a distance, and conducting data analysis. The data sources described below were used for the educational research; some of these data were also used by the ethnographer. Additional data were collected for the science and ethnography portions of the project, but are not included here.

Data Sources

Evaluation of the educational program was conducted using a wide variety of data. First, all online seminar video sessions were recorded and reviewed for student interaction. We also conducted interviews with participating scientists and students at the beginning of the TREET project, at the conclusion of the spring seminar, on the last day of the cruise, and after student presentations of their research analysis. Scientists and students completed surveys that focused on the effectiveness of the seminar and cruise. They also completed logs during the cruise in which they reflected on conducting research by telepresence and on how the students engaged with their research and with other participants. We took extensive observation notes during the cruise. Logs, surveys, interviews, and some seminar videos were subjected to qualitative analysis.

Our objective was not to evaluate the merits of student projects—that was the responsibility of the professors. Instead, we analyzed students' work and presentations in order to characterize student participation in each phase of the project and to describe more generally what students learned both in content and in research skills. We identified themes within and across the many data sources and examined the implications of these themes in describing and evaluating the implementation of the educational program.

Student Research

During the TREET project, students met the objectives of engaging in all phases of research. For all students, it was their first experience with designing a research plan that included remote data collection (or any data collection) and data analysis.

Students were provided with a guide to help them develop their research projects, including identifying a hypothesis, designing a methodology by describing data to collect and location of the sampling site, identifying ROV sensors or other tools, and defining an analysis plan. They worked with their professors to flesh out their research plans. During the seminar, the scientists offered feedback when students presented their plans. Table III shows the diversity of student projects, the data collected during Phase II, and the analysis they completed in the final phase of the project. Each student presented digital slides describing his or her research plans. Students chose topics that interested them, even if that meant relying on tools and expertise beyond that provided by the mentor. The presentations revealed that all students exhibited an understanding of the field site.

During the fieldwork, students were most engaged when the ROV was collecting data necessary for their own research. They told the *Hercules* pilot where to navigate, helped design mapping routes, and made suggestions about which samples to collect. Shipboard personnel relayed weather and ocean conditions as well as information from past experiences about what was most practical for ROV maneuvering. Throughout the process, the students were supported by the scientists on both ship and shore.

Student E expressed great satisfaction and excitement at the fieldwork experience: "I came up with my dive plan and was pretty stoked . . . was talking back and forth with the scientists about my research and feel good." Student B said, "I did some important bubble imaging and photo mosaicing and feel much better about my project." Scientist Z observed, "[Student G] had a fantastic interaction to make sure the ship wasn't about to do a bad thing (we had better access to data than anyone on the ship). . . . [Student G] expressed that she really like taking ownership of decision-making responsibility as I guided her through what information we had and how to look at it."

It was also observed that most student growth occurred when they were responsible for guiding the data collection. Scientist V explained, "[T]oward the end I felt like Student A, E, or F would just pipe up and say, 'When you get a chance, can you go over there and take that measurement?' " He went on to explain that as the students gained confidence they communicated more directly and were clearer about their directions. Scientist Z said, "I think the experience for the students was great, they had as close as possible an authentic cruise experience on land, and as they collected their own data you could see their understanding of deep-sea research grow." Scientist Q said, "I noticed that the students stepped up more and more and took more of a leadership role, that was the intention all along."

However, some scientists were uncomfortable at times with student "ownership of decision making." The ISC watch leader reported, "[Student E] is running the watch tonight. I worry [Scientist V] has thrown him in at the deep end. There are things that I am not confident that [Scientist V] or [Student E] know well enough to communicate to the ROV pilots, so if I was [Scientist V] I would have been more protective." Scientist W commented on the same event: "On a real ship it is unlikely that an undergraduate would be allowed to direct an ROV dive so [Scientist V] is pushing things beyond. . . ." Scientist U on board the ship commented that undergraduates typically would not be engaging with the telepresence technology; it would be reserved for more senior personnel. Nonetheless, students experienced success and were able to collect data they had requested.

Students were then expected to analyze data collected during the cruise back at their home institutions and to share their work. Having made connections with the scientists from multiple institutions, students received help from the scientists via teleconference meetings and other means of communication. There was a great deal of variation of experiences and outcomes related to data analysis. Interviews with scientists who worked directly with students as well as with the students themselves revealed that the timing for when students had access to their data after the field experience was a significant factor in their ability to analyze it successfully. Students who experienced a long delay between the end of the cruise and receiving data "lost a ton of motivation, and by the time they got the data they were asking what were we doing with this," according to Scientist V. Student A, in particular, was discouraged because when she finally started data analysis, she realized that what had been collected did not reveal fluid flux, as she and her mentor had hoped it would, and she had little time to pivot and revise her research and analysis plan. She "learned that it doesn't always work out." Another student was considered lucky because he got his data one month after the cruise.

Having an adequate amount of time to accomplish work given an undergraduate student's schedule was difficult. Unlike graduate students undertaking similar research, undergraduates had classes to attend and were limited to semester grading periods. Nonetheless, at the end of the spring semester of 2015, the students presented their data analyses and described remaining work that could be done. For some students, the presentation to the TREET team via teleconference was the culmination of the project while others continued working. We did not evaluate the scientific quality of each student research project per se, instead relying on the participating professors to evaluate the work of their students. However, a measure of student success is their overall productivity. The following describes student accomplishments: two TREET students presented their results at professional conferences (Students B and F), one student published an article (Student D), three students went on a research cruise following TREET (Students B, D, and E), and three students plan to go to graduate school to study ocean sciences (Students B, C, and E).

Real-World Science

The seminar provided multiple examples of scientific dialogue as well as professional camaraderie among the scientists. All eight students mentioned in postseminar interviews that they enjoyed witnessing the scientists' discourse in the seminar. Student D said she particularly liked that she was able to see how specialists interact and share ideas; she commented that they asked creative questions that made her think about things in a different way. Similarly, in an anonymous postseminar survey, two students reiterated that the strength of the seminar was in "having a variety of scientists [give] different perspectives on problems" and having access to "professors' knowledge and expertise." However, student engagement in the discussions was low and there was decreasing engagement in the blog over time. Student F noted in an interview, "[T]here seemed to be a high ratio of scientists to students. I know that it would be difficult to change this, but speaking for myself I was a bit intimidated at times." Scientists Q, E, and R respectively also commented that such a seminar would be better served if they could "find a way to hear from the students" and think about "ways to get better engagement on the part of students" or "some kind of more interactive process." Though scientists and students alike thought the presentations and group discussions during the videoconferencing sessions provided a great forum for ideas, questions, and concerns, students mostly maintained a listening role.

Fieldwork

Because undergraduate students are not familiar with fieldwork in ocean science or in research generally, most students had little conception of doing real-world science. Therefore, bringing students up to speed was a gradual process. As Kent et al. (1997) describe field experiences on a continuum, the TREET students' experiences evolved considerably, from observing during the seminar and early in the cruise, to increasing confidence and participation, to full engagement at the point they directed the ROV from shore and conducted their own data analysis.

During the "observation" stage, early in the cruise, students on watch typically did little other than observe as the scientists on ship and on land communicated with each other. The chief scientist thought that the best way to get a feel for the ebb and flow of the fieldwork was to mirror the ship's watch roles, so students were encouraged to record observations of the undersea geology and biology while watch standers onboard the ship did the same. Several students expressed boredom during these early watches. They said, "pretty slow watch day, not too much happened" and "Pretty boring day! [It] would have been more fun to be on the cruise, or to have cancelled the watch when mapping plans were decided on, since the people ashore didn't play much of a role in decision making or participation." Nevertheless, students gained experience with the communication tools and a familiarity with what to look for as the ROV maneuvered. Student D highlighted this point, "[I] observed the mapping and watched how [Scientist X] brought in her data." Student B said, "I have come to learn that even though we are doing pretty much the same thing for all 6 h of our watch, it is extremely exciting to be involved in this 'real science' as well as being able to listen to the chatter between all the scientists in real time."

Authentic Research

Students experienced the real-world scientific challenges involved when working at ocean depths while engaging from a distance. Early in the cruise, there was some difficulty with the ROV. The crew on the ship explained that the ground fail went to zero and the ROV seemed very heavy. Upon recovery of the ROV (which was difficult due to currents), they noted that one of the "science bottles" holding the laser spectrometer had failed and taken on water, and although it did not affect the function of the ROV, it did affect the scientific tool. The students saw firsthand how the engineers and scientists figured out not only how to recover the ROV, but also how scientists on ship and shore (the engineer for the laser spectrometer was in Rhode Island) together determined whether or not they could fix the tool for later dives during this cruise. Student D commented, "I thought it was pretty cool to see the laser spec being taken apart and seeing what was happening with it. . . . I was surprised at how much can go wrong so fast."

Telepresence Cruise Operations

The distribution of expertise on any given day was unique to this cruise, in that the knowledge base sometimes resided with a scientist sitting next to the ROV pilot and at other times resided with a student or scientist sitting thousands of miles away at the ISC. At times, undergraduate students located in Rhode Island were directing the data collection; at other times, scientists whose tools were being deployed by the ROV pilots were watching the video from a remote location. The most obvious challenges, therefore, were figuring out the line of command. Who was in charge at any given moment? When an ROV pilot had questions, did those on watch sitting next to the pilot know and understand what requests were being made from scientists and students on shore? Scientist W on board the ship explained that, in the beginning in particular, it was hard to remember that there were times when the shore was supposed to be "calling the shots." In addition, there was a general problem of the students' lack of experience. Scientist T explained, "[O]ften, I felt a disconnect between what an undergraduate student might think is possible—they have never been on a ship, never seen an ROV, never experienced conditions at sea—I had to remember that I would ask the same naïve questions myself at first."

IMPLICATIONS AND LESSONS LEARNED

The overall experience was valuable to students on many levels. All students appreciated interacting with the entire community and said they would recommend the experience to other students. Postcruise and final interviews highlight the students' positive views. Student D said, "For me, most was a huge learning experience. At the beginning everything was new, I was learning a lot and it was cool to watch everything and see communication with people that were actually on a cruise . . . how the technology is used, or seeing how experiments are done." Student B also said, "It's a very cool thing to be able to see the bottom of the ocean via live video streams, be in constant contact with scientists, PhDs, and engineers controlling the ship, running research, and make decisions." "[T]he most valuable part was interacting with all the different scientists," said Student D. "I would absolutely recommend the experience to a friend. . . . They get to see how research is done and meet interesting people," said Student A.

There were many important lessons learned from the TREET educational program that should inform future implementations of research experiences that include telepresence as a key component. First, the schedule should be evaluated carefully—from the timing and length of the overall research opportunity, to the timing of the cruise or other remote fieldwork, and the timing of watch schedules. By having telepresence replace fieldwork, it may reduce the stress and cost of planning for travel, but it does not change the overall need to plan the schedule with the students. (In the case of TREET, students traveled to the ISC in Rhode Island, though they did not travel on the cruise. In the future, if a command center is located at a school, students would not need to travel at all.) The length of the TREET experience, which took place over three academic semesters and a summer, proved difficult for some students. Clear planning and scheduling is critical, though anything less than two semesters might reduce the likelihood of students experiencing all aspects of research.

Research includes both data collection and data analysis. However, getting data proved to be challenging for many of the undergraduates, who had to rely on data being retrieved from the ship and processed by scientists and postdoctoral researchers at other institutions with competing requests and time constraints. Planning for postcruise support is necessary to ensure that students get the data from the ship as quickly as possible. Alternatively, students could get access to raw data and learn how to process the data.

The online seminar was serendipitously the first step of working together and building community, and not very different from what occurred during the telepresence-enabled cruise. Having the experience of students interacting with team members at a distance and being part of a larger community is important. The cruise itself was a hybrid cruise with many crew members aboard the ship conducting "business as usual" and not participating in TREET, while scientists and students on shore were trying to conduct research in a new way. Student A expressed it this way: "I got here and figured out the whole project was a lot bigger than what the [seminar] sessions led on, the [seminar] sessions didn't talk about other scientists on the ship, other students, and other watch leaders all doing their own thing. All of that was a huge surprise." This will likely be true in future telepresence research opportunities, so it will be important to learn how to be integrated appropriately into the larger context.

For telepresence to work, communication between ship and shore is critical. In particular, ship scientists and staff need to keep in mind when communicating with students that undergraduates have less experience and may need and appreciate some explicit advice and handholding. Soon after the cruise began, the community and the camaraderie formed, although there was a division between the ship community and the shore community. Such divisions may become less noticeable as this mode of research becomes more common.

Science proficiency requires apprenticeship under the tutelage of master scientists and through peer-to-peer interactions. In the field setting, students have the opportunity to learn from nature and about science as a social enterprise (Mogk and Goodwin, 2012). Being exposed through telepresence, students were grounded in actual practices of scientists in the field, not simply the reports through which science findings are made known. Additionally, students were exposed to scientific discourse, problem solving, and the use of scientific sensors and tools.

Much of what we explored in the educational part of the TREET project was the question of the degree to which we could include undergraduates in a telepresence-enabled cruise in which students were engaged in conducting all aspects of research. Like REUs, TREET students were able to participate in the full arc of the research experience, in that telepresence was able to provide similar affordances as going into the field, such as making observations, collecting samples, and taking measurements. However, telepresence was a stand-in for the fieldwork portion of research, and students used remote sensors and tools to interact with the environment.

CONCLUSION

The educational goals of the TREET project were to provide opportunities for undergraduate students to conduct research in oceanography. This paper describes the students' experience and explores the implications of using telepresence as a tool for engaging students in research. Perhaps the most exciting outcome is the potential of telepresence to recruit and train next-generation researchers, bringing novices into ocean science "fieldwork" alongside experts and allowing undergraduate students to experience real-world research from beginning to end in a field of study that would otherwise be inaccessible. The lessons learned will help in planning for the next step in making undergraduate research using telepresence a new norm.

The TREET project successfully, if modestly, offered a rich learning experience and prepared a small cadre of students to participate in all aspects of the research. Indeed, it was amazing to witness the confidence of undergraduate students as they helped to make research decisions, especially since the research sites were thousands of miles away and visible only through video feeds and other telepresence technology.

The TREET project was a seminal step in imagining how a new workflow with undergraduates participating in remote-based research could happen. As new command centers are becoming more ubiquitous—there are 12 to date and more on the way in the ocean sciences alone—this method of conducting research with undergraduates could become more common. Telepresence research does not replace the experience of going out to sea, but it can be as engaging and has the potential for providing opportunities that could not otherwise have happened.

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REFERENCES

Bauer, K.W., and Bennett, J.S. 2003. Alumni perceptions used to assess undergraduate research experience. *The Journal of Higher Education*, 74(2):210–230.

Bell, K.L.C., German, C.R., Mirmalek, Z., and Pallant, A. 2015. Transforming remotely conducted research through ethnography, education, and rapidly evolving technologies (TREET). *Oceanography Supplement*, 28(1):40–43.

Brothers, L.L., Van Dover, C.L., German, C.R., Kaiser, C.L., Yoerger, D.R., Ruppel, C.D., Lobecker, E., Skarke, A.D., and Wagner, J.K.S. 2013. Evidence for extensive methane venting on the southeastern U.S. Atlantic margin. *Geology*, 41(7):807–810.

Bruce, G., Semken S., Anbar A., Karstorm, K., and Crossey, L. 2014. Explore and study Grand Canyon by immersive virtual field trip! Abstract. *Geological Society of America Abstracts and Programs*, 46(6):91.

Campbell, A.M. 2002. The influences and factors of an undergraduate research program in preparing women for science careers [Unpublished doctoral dissertation]. Lubbock, TX: Texas Tech University.

Carlson, C.A. 1999. Field research as a pedagogical tool for learning hydrogeochemistry and scientific-writing skills. *Journal of Geoscience Education*, 47:150–157.

Elkins, J.T., and Elkins, N.M.L. 2007. Teaching geology in the field: Significant geoscience concept gains in entirely field-based introductory geology courses. *Journal of Geoscience Education*, 55:126–132.

Feldman, G.C., and Viola, T.C. n.d. JASON Project: Telepresence. Available at http://seawifs.gsfc.nasa.gov/jason/HTML/TECHNOLOGY_telepres.html (accessed 17 June 2015).

Fowler, C.J.H., and Mayes, T. 1997. Applying telepresence to education. *BT Technology Journal,* 14(4):188–195.

Fuller, I., Edmondson, S., France, D., Higgitt, D., and Ratinen, I. 2006. International perspectives on the effectiveness of geography fieldwork for learning. *Journal of Geography in Higher Education*, 30(1):89–101.

Halstead, J.A. 1997. Council on Undergraduate Research: A resource (and a community) for science educators. *Journal of Chemical Education*, 74:148–149.

Hensel, N., ed. 2012. Characteristics of excellence in undergraduate research. Washington, DC: Council on Undergraduate Research.

Hopper, L.J., Schumacher, C., and Stachnik, J.P. 2013. Implementation and assessment of undergraduate experiences in SOAP: An atmospheric science research and education program. *Journal of Geoscience Education*, 61(4):415–427.

Hunter, A.-B., Laursen, S.L., and Seymour, E. 2007. Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. *Science Education*, 91:36–74.

Kardash, C.M. 2000. Evaluation of an undergraduate research experience: Perceptions of undergraduate interns and their faculty mentors. *Journal of Educational Psychology*, 92:191–201.

Kent, M., Gilbertson, D.D., and Hunt, C.H. 1997. Fieldwork in geography teaching: A critical review of the literature and approaches. *Journal of Geography in Higher Education*, 21(3):313–332.

Kinkead, J. 2003. Learning through inquiry: An overview of undergraduate research. *New Directions for Teaching and Learning*, 93:5–17.

Kintisch, E. 2013. A sea change for U.S. oceanography. *Science*, 339(March):1138–1143.

Knapp, E.P., Greer, L., Connors, C.D., and Harbor, D.J. 2006. Field-based instruction as part of a balanced geoscience curriculum at Washington and Lee University. *Journal of Geoscience Education*, 54(2):103–108.

Nagda, B., Gregerman, S., Jonides, J., von Hippel, W., and Lerner, J. 1998. Undergraduate student–faculty research partnerships affect student retention. *The Review of Higher Education*, 22(1):55–72.

Niemitz, J.W., and Potter, N. 1991. The scientific method and writing in introductory landscape laboratories development. *Journal of Geological Education*, 39:190–195.

Mogk, D.W., and Goodwin, C. 2012. Learning in the field: Synthesis of research on thinking and learning in the geosciences, *In* Kasten, K.A., and Manduca, C.A., eds., Earth and mind II: A synthesis of research on thinking and learning in the geosciences. Geological Society of America Special Paper 486. Boulder, CO: Geological Society of America, p. 131–163.

Rowland, S.M. 2000. Meeting of minds at the outcrop, a dialogue-writing assignment. *Journal of Geoscience Education*, 48:589.

Russell, S.H., Hancock, M.P., and McCullough, J. 2007. The pipeline: Benefits of undergraduate research experiences. *Science*, 316(5824):548–549.

Sadler, T., Burgin, S., McKinney, L., and Ponjuan, L. 2010. Learning science through research apprenticeships: A critical review of the literature. *Journal of Research in Science Teaching*, 47(3):235–256.

Seymour, E., Hunter, A.B., Laursen, S.L., and Deantoni, T. 2004. Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Science Education*, 88:493–534.

Stokes, A., and Boyle, A.P. 2009. The undergraduate geoscience fieldwork experience: Influencing factors and implications for learning. *In* Whitmeyer, S.J., Mogk, D.W., and Pyle, E.J., eds., Field geology education: Historical perspectives and modern approaches. Geological Society of America Special Paper 461. Boulder, CO: Geological Society of America, p. 291–311.

Van Dover, C.L., German, C.R., Yoerger, D.R., Kaiser, C.L., and Brothers, L. 2012. Telepresence field research experience for undergraduate and graduate students: An R/V Okeanos Explorer/AUV Sentry success story. Paper presented at the American Geophysical Union, Fall Meeting, San Francisco, CA. December 3–7.

Wagner, J.K.S., McEntee, M.H., Brothers, L.L., German, C.R., Kaiser, C.L., Yoerger, D.R., and Van Dover, C.L. (2013). Cold-seep habitat mapping: High-resolution spatial characterization of the Blake Ridge Diapir seep field. *Deep Sea Research Part Ll: Topical Studies in Oceanography*, 92:183–188.