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Telepresence-enabled remote fieldwork: undergraduate research in the deep sea

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ABSTRACT

Deep-sea research is rarely available to undergraduate students. However, as telepresence technology becomes more available, doors may open for more undergraduates to pursue research that includes remote fieldwork. This descriptive case study is an initial investigation into whether such technology might provide a feasible opportunity for undergraduate students to conduct ocean science research remotely, and if so, whether students can move from being spectators to beingactive agents. Specifically, we inquire into the learning of seven students who conducted fieldwork via telepresence, which enabled them to participate in a cruise that used remotely operated vehicles to explore an active underwater volcano and mud volcano cold seeps. This study examines whether the students engaged in authentic research and whether telepresence provided a reasonable experience of fieldwork at sea. Interviews and observation notes suggest that these undergraduates were able to undertake all aspects of research. Students' presentations exhibit a great deal of knowledge about the field sites and show that they contributed findings from their analyses. This study constitutes important initial evidence that telepresence can provide effective approximation of the experience and educational value of fieldwork at sea, and suggests that telepresence is a feasible option for future undergraduate research experiences.

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Deep-sea research; oceanography; undergraduate; case study; learning outcomes

Introduction

Telepresence is triggering a paradigm shift that expands undergraduate research opportunities (UROs). This paper is a descriptive case study of a project that trialled the use of telepresence as a means for undergraduate students to conduct remote deep-sea fieldwork. The project was designed to advance research experiences for undergraduate students, for whom opportunities for deep-sea research are practically non-existent. An unanswered question is whether UROs can successfully incorporate telepresence as a tool for conducting authentic research. Specifically, it is unknown what skills and knowledge students can attain when telepresence is used at the core of their research experience. We contribute an

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initial answer by characterising the results of student participation in a National-Science-Foundation-funded exploratory project: *Transforming Remotely Conducted Research through Ethnography, Education and Rapidly Evolving Technologies* (TREET).

It is widely accepted that learning is often best done with a hands-on approach and when interacting with others (Driver, Asoko, Leach, Scott, & Mortimer, 1994; Singer, Nielsen, & Schweingruber, 2012; von Glasersfeld, 1989), and that much learning is context-dependent (Brown, Collins, & Duguid, 1989; Jonassen, Davidson, Collins, Campbell, & Haag, 1995). Siemens (2014) proposes that decision-making itself is an important learning process. These areas of pedagogical theory suggest that UROs, in general, and fieldwork, in particular, should provide valuable learning experiences. In fact, UROs have been shown to benefit undergraduates (Russell, 2006). Lopatto (2004) found that when students participate in authentic UROs, they gain in *tolerance for obstacles, understanding real problems,* and *understanding how scientists think*. Studies of research apprenticeships report that *scientific content knowledge, science skills*, *confidence*, and *self-efficacy* can improve (review by Sadler, Burgin, McKinney, & Ponjuan, 2010).

Telepresence is becoming more pervasive and is now sophisticated enough for educators to imagine how it might be used to support UROs. In cases where fieldwork is impossible – due, for example, to a lack of resources or in a location that is too remote, dangerous, or impractical – telepresence may be able to provide a reasonable alternative for engaging in authentic research. Ideally, students could have both the sense of 'being there,' promised by telepresence, and meaningful engagement in learning skills and concepts associated with fieldwork. The goal for the pilot project was that through the use of telepresence technologies, undergraduate students could participate in research activities from planning to fieldwork, which was a central portion of their deep-sea research project, and in doing so could move beyond being spectators to being active agents in their own authentic research.

Purpose statement

The purpose of this study is to characterise qualitative evidence of student learning that occurred during a pilot project that involved undergraduates in telepresence-enabled deep-sea research. Our interrogation of the numerous data sources was guided by asking whether there was evidence for student learning during the remote fieldwork, whether the learning was of kinds documented in the literature for more conventional undergraduate fieldwork, whether students were actively participating in the research or were passive observers, and to which science content and scientific research practices students were being exposed.

Literature review

Authentic research

Cohen (1998) described Student and Scientist Partnerships (SSPs) as 'an exciting new force in science education and possibly in science itself' (p. 1), and asserted that they were rapidly expanding the nature of science education throughout the world. According to Cohen (1997), in SSPs: scientists use students to help answer questions that have not been fully addressed; students gather and analyse data, and so are involved in projects that involve authentic and important scientific questions; and science teachers are active intermediaries not only for explaining science, but also for helping students implement their research. This is also an apt description of many of today's UROs. However, as UROs become more popular, a question presents itself as to what extent they live up to these objectives, and whether the practice of having undergraduates 'do science' does, in fact, lead to the positive outcomes many have predicted for them. Sadler et al. (2010) conducted a review of studies of UROs and other apprenticeship experiences for students. Three of these were large studies of UROs (Bauer & Bennett, 2003; Lopatto, 2004; Russell, 2006; summarised in Russell, Hancock, & McCullough, 2007) with *n* ranging from 986 to 4560. These studies showed gains in scientific content knowledge and in many science skills, including *theresearch process, communication, database information retrieval, understanding primary literature, computer applications* used in data analysis, *teamwork,* and *working independently*. Other studies of UROs have found that both the student and the research community benefit from student participation (Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998). Some have found that student researchers' level of involvement correlated positively with their satisfaction (Campbell, 2002; Russell, 2006; both as cited in Sadler et al., 2010; also see Russell et al., 2004) and perception of gains (Russell, 2006; as cited in Sadler et al., 2010). All of these results indicate that UROs can be a valuable experience for many students. On the other hand, Sadler et al. question how much science content was learned in these experiences and the depth of understanding developed.

Fieldwork

Participating in *fieldwork* as part of an URO significantly enhances students' engagement, understanding of content, and interest in the field, according to Fuller, Edmondson, France, Higgitt, and Ratinen (2006). Field experiences provide a range of learning opportunities that laboratories cannot supply (Lock, 1998). Frodeman (2003) suggests that field research develops both scientific inquiry skills and knowledge characteristics associated with experts. Additionally, Frodeman notes, field research helps students place geological concepts in their environmental context. Hoskins and Price (2001) describe how field experiences provide important opportunities for mentoring students. Gonzales and Semken (2006) found that a field-based approach to teaching igneous petrology resulted in students who were highly engaged and were more responsible for their own learning. Russell et al. (2004) determined that a primary correlate with the gains they found for the National Science Foundation's Research Experiences for Undergraduates (REU) Programme was 'having done something that seemed like real research' (p. 5). Unfortunately, engaging undergraduate students in a programme of deep-sea research that includes fieldwork has been virtually impossible before now, except for the rare student able to accompany his or her professor on board a ship. However, in TREET, fieldwork – conducted remotely during the cruise – was a core aspect of completing the research.

Telepresence-enabled education

According to Minsky (1980), the futurist Patrick Gunkel coined the term *telepresence* to convey the idea of remote-control tools. Minsky believed that the great potential of telepresence lay 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. In recent years, this technology has been adapted for oceanographic work, enabling scientists, teachers, and students to see live images and obtain real-time data from ships at sea. Ocean scientists have also explored ways to conduct telepresence-enabled autonomous underwater vehicle[1] research (Brothers et al., 2013; Wagner et al., 2013) and to connect landlocked scientists with colleagues at sea (Ballard & Durbin, 2008; Kintisch, 2013).

With Jason Learning (http://www.jason.org), Robert Ballard pioneered the use of telepresence for ocean science education where students could observe the seafloor from a distance. The earliest use of telepresence in ocean education could be thought of as similar to virtual field trips (VFTs) – a way to augment instruction and allow students to experience the world outside their classroom. VFTs are intended to provide much the same experience – albeit a limited one – as an actual field trip. Typically, during a VFT, students move through a series of interactive experiences designed to maximise learning and to mimic the real (yet distilled) world that they would have experienced in the field (Garner & Gallo, 2005). Spicer and Stratford (2001) found that VFTs are a growing part of the undergraduate experience in some universities; however, they suggest that VFTs should not be used at the expense of real fieldwork. Unlike VFTs, telepresence has the potential to allow students to see and interact with the real world with all its richness and unpredictability, rather than with a world that was designed for a controlled learning experience. As telepresence technology has become more widely available, educators have explored ways to move from a passive, witnessing approach to a broader use, where students are actively engaged in the learning (Fowler & Mayes, 1997). However, one previously untapped potential has been the use of telepresence to engage undergraduate students in authentic research in which they develop a research hypothesis, create a research plan, experience the distant environment, collect data remotely, analyse those data, and interact with the scientific community. Unlike VFTs, the telepresence experience takes place in the real world in real time. One goal of TREET was to elucidate additional ways to use telepresence throughout science and engineering fields to excite, train, and recruit next-generation researchers.

Context for the study

The Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) programme of the National-Science-Foundation funded TREET to explore ways to use remotely operated underwater vehicles (ROVs) and telepresence to provide scientists and students opportunities to engage in deep-sea research from a distance. The project included 10 ocean scientists, an ethnographer, and three education researchers (the authors). The education portion of the project, which is the focus of this paper, involved seven undergraduate students in conducting their own research from a remote location. Because undergraduates typically cannot direct research from a deep-sea exploration vessel, it was not known to what extent they would be able to engage in their own authentic research. If they could take part successfully in such an experience, it would indicate that telepresence technologies have the potential to produce transformational changes in the way students are introduced to ocean science. More detail about the implementation of the project is available in Pallant, McIntyre, and Stephens (2016).

TREET was conducted in three phases: (1) a preparatory seminar; (2) a two-week telepresence-enabled research cruise; and (3) a post-cruise seminar, data analysis, and reporting of results. The first phase consisted of a hybrid-learning environment, with both an online seminar and face-to-face meetings between the undergraduate students and their mentors (three of the ocean scientists; see the next section). The seminar consisted of 12 weekly hour-long sessions using video-conferencing software, supported by a password-protected website that included assigned readings, resources, videotapes of the synchronous sessions, and places for open discussion. In the second phase, which was the heart of the telepresence-enabled fieldwork and is the focus of this paper, participants travelled to the Inner Space Center (ISC) at the University of Rhode Island's Graduate School of Oceanography and to the Woods Hole Oceanographic Institution (WHOI) to participate in remote fieldwork. The ISC and WHOI were both equipped with multiple large monitors that connected the ship to shore via streams of video, audio, and data, as well as computer stations for each student and scientist (Figure 1). Technical support staff was available on ship and shore at all times. Students monitored instrument readings from the E/V *Nautilus* and the ROV *Hercules*, communicated with ship by audio and text, and directed data collection (under supervision) during periods focused on their individual research objectives. During the third phase, students analysed some of the data they collected, participated in a five-week seminar during which they shared their work with the team, and in some cases, shared their work at professional ocean science conferences.

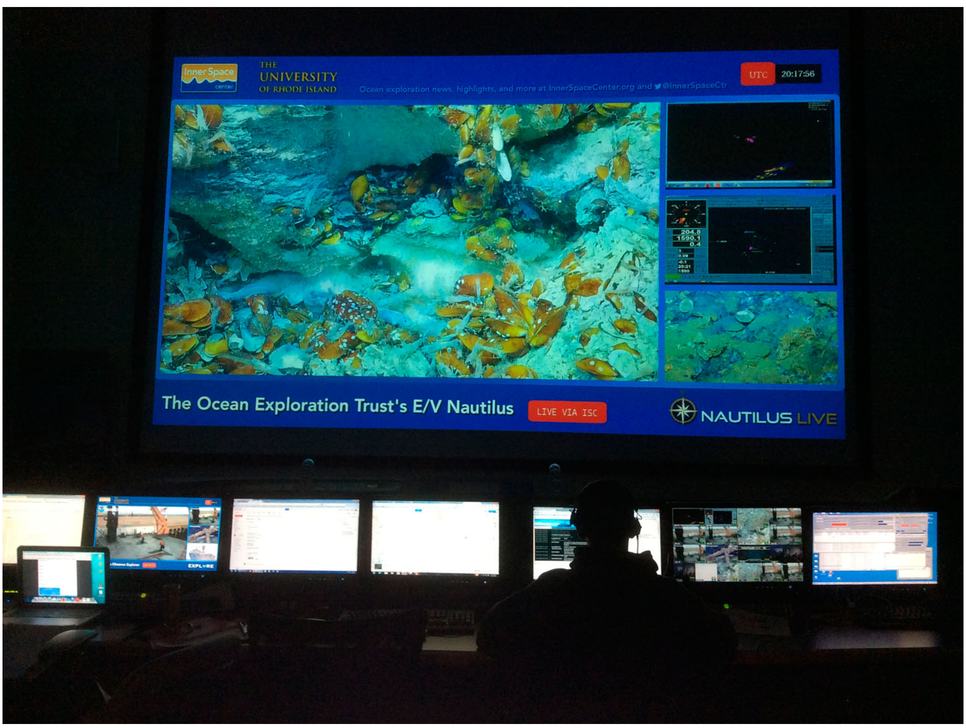

Figure 1. Mission Control at the ISC with student standing watch (in silhouette); large video feed covers much of the wall (photograph by Zara Mirmalek; used with permission).

This study focuses on the telepresence-enabled data-collection phase and on what students learned during this remote fieldwork.

Student and mentor participants

Three professors from Harvard University, Michigan State University, and the University of Idaho recruited eight undergraduates to participate in TREET and acted as their mentors during the project. According to the professors, they attempted to recruit students who had demonstrated aptitude for science in their coursework and interest in doing research, although for most of the students, their career plans were in flux. On a questionnaire, three of the students listed prior research experiences related to oceanography (not all of it fieldwork): coral disease research conducted in Cuba at the Center for Marine Studies; a weeklong field trip to Panama to study marine invertebrates plus experience logging photographs and videotapes at the Ocean Exploration Trust; and geophysics research (in a laboratory). One student dropped out of the programme before the remote fieldwork phase. Other student demographics are in Table 1.

Methods

Our objective in the present study is not to provide *numerical measures* of gains, as each student's research topic, experience, and access to data collected in the field were different, and no one pre/post-test would be suitable for content assessment. Rather, we wish to *characterise* students' learning of research skills and science content; describe their insights into understanding real-world scientific research; and suggest factors that could account for these observations. Given these objectives, the small *n*, and the richness of our data sources, we used qualitative case study methods to help make sense of our large corpus of data. We did not attempt to establish countable codes, as is often done in a thematic analysis, but to develop descriptive observation categories to help us characterise evidence for learning from a large number of data sources. Although our method did not allow us to establish the frequency of any particular type of evidence being described (of doubtful value, given the small *n* and uniqueness of each student's research programme), it did allow us to make a reasonable determination of whether a descriptor was meaningful in characterising the experience of more than one student and whether similar evidence had been noted by more than one observer.

Table 1. Summary demographics of student participants.

Institution		Gender		Year		Major		Prior fieldwork experience	
U. Idaho	2	M	3	Soph-Jr	1	Biology	1	No	6
Harvard	2[a]	F	5[a]	Jr-Sr	6[a]	Anthropology	1[a]	Yes	2[a]
Michigan State	4			Sr-Grad	1	Geology	5		
						Geological Sci. & Physics	1[b]		

[a]One student dropped out after the introductory seminar.
[b]Double major.

Data sources

Although the focus of this study is on what students learned during the remote fieldwork, we began by reviewing data sources from the entire project. These included student notes and presentations before and after the fieldwork and after the data analysis period; semi-structured interviews with the students and their mentors at four points during the project, bracketing the remote fieldwork period;[2] two semi-structured interviews with each of the other ocean scientists; daily surveys completed by students, mentors, and other onshore and shipboard scientists during the two weeks of remote fieldwork; observation notes taken by the education researchers during the remote fieldwork;[3] and online chats between ship and shore, recorded as a regular part of telepresence cruises.

All of these data were reviewed for evidence of student learning and engagement in the research, as well as for broader aspects of student and mentor experience that could have implications for the planning of future telepresence projects. Many of these broader aspects have been addressed in a related paper, Pallant et al. (2016). In this study, we focus on those data that help us characterise student learning by looking at changes in student presentations and by drawing on information from the interviews, daily surveys, observation notes, and online chats.

Data analysis

For each data source, an author reviewed the data, making notes and organising data into observation categories, and developing descriptors for the categories. A second author then reviewed a substantial portion of those data (the amount varied, but ranged from approximately a fifth to all of those data, depending on the size of the data source), organising them into the same categories. As a team, the three authors resolved all discrepancies by discussing to consensus, and then discussed the meaningfulness of each descriptor in light of the goal of characterising student learning (see bolded examples in Appendix 1). The student presentations were analysed by comparing specific aspects at different points in time to see how each aspect had evolved (see Appendix 2). Wherever references to student learning and participation in research were noted in the authors' daily observation notes or in the daily survey responses of the mentors and shipboard scientists, these references were flagged and summaries were written of the relevant passages. The authors then brought together the written characterisations of all the data types to see what broader categories and descriptors emerged across the data sources and which of these could provide the most insight into the kinds of student learning taking place.

Results

During the two weeks at the ISC, students engaged in telepresence-enabled fieldwork, including making observations, collecting data, making decisions, and communicating with the ROV pilot, scientists, the public, and their peers. The state-of-the-art technologies at the ISC and WHOI enabled immersive experiences strikingly similar to that of more traditional fieldwork and appeared to provide students with learning experiences that fostered growth in their understanding of the field sites and of how ocean science is conducted. The following results highlight student learning during the remote fieldwork and their direct participation in the data and sample collection, though the discussion will also, of necessity, include aspects of their preparation for fieldwork along with their analyses of data and presentations of findings following the fieldwork.

Participation of students during observations from a distance

There had been little discussion about the day-to-day expectations of the telepresence-enabled fieldwork during the introductory seminar; so, during the first two or three days of the cruise, students mainly observed and learned about the communications technology at the ISC. However, this changed around Day 3. On that day, one shipboard scientist commented in his daily survey, 'The students at ISC did a great job [updating] the science chat with information about the current dive conditions.' That same day, one of the mentors wrote, 'Today was much better with respect to student participation. [It] seemed that the students were engaged throughout the day … .' Observer notes, the online chat log, and scientists' daily surveys all indicate that, very quickly, students were able to contribute by exploring the video feed from the ROV, recording notable observations in the science chat log, and conveying these observations over headset to those on board the *Nautilus*.

Student exposure to scientific discourse

An unexpected outcome not typically associated with UROs, and made possible by telepresence, was extended exposure to real-world scientific discourse among a sizable group of practicing scientists. All of the students, in their daily surveys and interviews, said they appreciated hearing the back-and-forth between the experts. In an interview, one student elaborated,

> I think that the dialog between scientists is really great … . It's a chance to see how peers who work in the same field but who are specialists in different things within that field interact, and how they share ideas about things they know a lot about with people who are studying other things, … seeing that collaboration at that higher level is a really good example for us as students, … when the scientists are … talking about things they are hoping to do, and other scientists say, 'Oh, have you thought of this technique or have you thought of that idea? So this works great, maybe you could apply it, too.' I think it's great to see those interactions … . So it's cool seeing that and using them as an example for collaboration.

Some of these students had never before observed scientists discuss scientific problems. All students said they found the opportunity to witness such interaction to be a valuable experience.

Changes in student communication with mentors and other scientists

Scientists noted in their daily surveys and interviews that as the cruise proceeded, students seemed to gain in skills and confidence. Although the students initially were hesitant to speak up, after the first couple of days they became much more comfortable asking questions of ISC and shipboard scientists and initiating contact. By Day 5, one shipboard and three shore-based scientists commented that students were engaging much more in conversations with the ship. Excerpts from scientists' daily surveys include the following:

> This was a GREAT day for student participation.
>
> Great to include students in the ISC in answering questions.
>
> I think the students are getting more used to the ISC and more willing to talk to Nautilus.

In their surveys, scientists were asked whether student questions and interactions were typical of those that happen onboard a ship. Eight of the 10 ocean scientists noted at least once that the questions or interactions were typical. On Day 5, one shore-based scientist (who had been on many cruises) wrote, 'These interactions were better than what typically happens on ship.' On Day 7, a shipboard scientist wrote, 'At sea more of the day to day life would be included in the interactions and questions but at the ISC more of the interactions and questions are about the science.' Five of the scientists (ship and shore) were consistent in saying that student responses were typical or better, while two shipboard scientists thought on some days the student questions exhibited less situational awareness (ability to comprehend critical elements related to shipboard data collection such as weather and currents) than would those of shipboard students. However, the third shipboard scientist, who consistently stated that the student questions were typical or better than questions from new shipboard participants, noted that students used their questions to establish situational awareness: 'When I was talking to [a student] at ISC he was asking questions typical of those on the ship, such as how long to target site and how are the currents. Mostly situational awareness questions.'

Changes observed during student direction of telepresence-enabled data collection

As the research moved to the two site locations where student data would be collected, at the Kick 'em Jenny submarine volcano off the coast of Grenada and the Barbados mud volcano cold seeps off Trinidad, each student occupied the so-called watch leader's chair and helped direct data collection. Students did so by communicating to the ROV pilots and the chief scientist on watch while the mentoring scientists offered support and advice. Shipboard personnel relayed weather and ocean conditions as well as information from past experiences about what was most practical for manoeuvring the ROV and the order of ROV operations. Students were thus supported as they helped to lead the dive, applying what they had learned in order to implement their research plan in the real world.

In interviews, three of the scientists on board the *Nautilus*, whose interactions with the students were exclusively through remote means (mostly audio), mentioned observing an increased confidence and sense of agency when each student directed his/her own research. One shipboard scientist, who said the students had definitely changed, commented that they began to take on more of a leadership role, willing to ask over the headset, 'When you get a chance, can you go over there?' The observers witnessed similar shifts at the point each student directed data collection. For instance, a week into the cruise, one of the authors wrote in daily observation notes:

> Ship asks [shore-based scientist a question] and [he] defers to [a student], 'Which is your priority, clam beds or steep seeps?' [The student] answers, also reminds them of [another ocean scientist's] research needs. She sounds confident, remembering her own needs as

> well as those of other scientists … . Later she skillfully declines to field a question from Sci Chat, 'We're a bit thin in here right now.'

The ship was looking for direction on where to send the ROV next, and when invited to, the student clearly stated her own priority, but also reminded the ship of the data collection needs of one of the scientists who was not in the ISC at that time. This mature communication differed markedly from the tentative communications from the students at the beginning of the cruise, and moved well beyond situational awareness questions to show an understanding of the needs of the larger project. When the undergraduates were allowed to direct data collection – although this is far from customary in ocean research – they appeared to grow quickly into a leadership role.

Problem-solving as observed from shore

Students' insights into how ocean research is conducted appeared to deepen considerably during the fieldwork. Telepresence was able to provide a window into real-world experience even though the action was thousands of miles from the students. A memorable experience occurred during the first week of the cruise when an important instrument on the ship broke. The students were able to watch closely as the scientists onboard took it apart, tried to diagnose the issue, and attempted to fix it, all while consulting via teleconference with a scientist onshore at the ISC who was the expert on this particular instrument. As the cruise continued, students experienced many things that can influence outcomes, including weather, currents, and finding more, less, or different phenomena than expected. In interviews at the end of the remote fieldwork phase, students indicated the value of being able to ask questions of scientists while watching them work. Three of the seven students mentioned learning about the necessity of flexibility when doing real-world science, and five commented that it had been beneficial watching the scientists problem-solve during the cruise.

It should be noted that despite witnessing the challenges, four students said afterwards in their interviews or daily surveys that they wanted to go on a cruise or that it 'would be cool to be on a ship.'

Student gains in knowledge of field sites and science via telepresence-enabled fieldwork

During the two-week cruise, the team investigated a range of interrelated biological, geochemical, and geophysical phenomena at the Kick 'em Jenny submarine volcano and the Barbados mud volcano cold seeps. Physical and digital data were collected from the water column and from the ocean floor.

Events during a cruise often necessitate revisions of research plans. Therefore, at the conclusion of data collection, the team gathered face-to-face and presented revised plans and goals for their projects. Students briefly stated the goals for their research, their original data-collection goals, the actual data that were collected, and their updated plans for data analysis. Comparing these presentations with their original plans indicates that four of the seven students had refined their research questions to reflect the cruise experience (see Table 2 for examples). The analysis plans now reflected the actual data that had been collected and were realistically correlated to how these data would help answer the research questions. One student did not present a data analysis plan, but instead presented a detailed list of data sources and from whom he would obtain each kind of data.

Students appeared to have grown noticeably with regard to understanding research; they presented tighter hypotheses that were directly correlated with data availability. One student wrote, 'With bubble data from [Researcher A] and the composition of the fluids from [Researchers B and C], I am going to be comparing how compositions affect temperatures, and fluid fluxes.'

Another student had initially stated her plan this way, 'Does the distributions [*sic*] of fauna surrounding the cold seep sites co-vary with temperature gradients, availability of resources and/or topological characters?' While at the ISC, a TREET scientist introduced this student to a postdoctoral fellow who was not a part of TREET. After long discussions between the two, this student reported more enthusiasm about her project. Her post-cruise presentation revealed that she had taken her plans for analysis in a new and more concrete direction, 'How does biodiversity associated with cold seeps vary from site to site?' Her data analysis plan was now much more clear and sophisticated: 'Quantify the biodiversity

Table 2. Growth of two student data-collection and analysis plans.

Hypothesis/Question	Analysis plan	Analysis	Feedback
Student A			
Pre-cruise: Identify the most likely way the next major landslide will occur, whether a sector collapse, an edifice collapse, a debris flow, or underwater landslide	Pre-cruise: Collect data mapping subsurface features		Feedback on pre-cruise plan: Scientists didn't believe that student would be able to collect data due to lack of technology on board ship and complication due to original hypothesis
Post-cruise: What are the different lithologies and facies [rock types and formations] that make up the debris avalanche?	Post-cruise: From video data create geologic map of rock types	Post-cruise: Used video, bathymetric [depth from ocean surface] data, and photomosaics to map the study area. Offered an interpretation of the results	Feedback on final presentation: A scientist suggested an alternative interpretation as to what the map may have revealed
Student B			
Pre-cruise: Is Kick 'em Jenny's collapse scar still active, and if so, is the down dropped portion continuing to creep down the slump scarp, or it behaving as a strike slip system?	Pre-cruise: Survey crater, collect photomosaics and magnetometer data to look for anything of interest		Feedback on pre-cruise plan: Scientists suggested getting video transects from earlier cruise to guide sampling; they also suggested that magnetometer data would be too much
Post-cruise: How is the area around Kick 'em Jenny behaving in terms of mass wasting [hydrothermal venting] processes?	Post-cruise: Complete survey along the scarp east and north of the crater, collect photomosaics showing areas of hydrothermal activity, collect temperature data and sub-bottom data	Post-cruise: Analysed photomosaics and bathymetric data, calculated percentage of area covered by biological mats to determine hydrothermal activity	Feedback on final presentation: Scientists were interested in how maps of biological mats might reflect change in fluid flow in hydrothermal system. One scientist suggested a possible alternative interpretation of data

of the seeps using random sampling statistics and a homemade GUI, courtesy of [the post-doctoral fellow]. Make an assessment of how the results quantify biodiversity, and interpret those results in relation to site variation.'

Student A (Table 2) had originally presented a hypothesis that involved the ability to predict phenomena based on past geological patterns. This type of prediction would have been difficult to prove because it was too broad, and scientists on the team helped him focus his efforts. The student's final presentation shows that the project evolved into one with a more attainable goal; the student successfully mapped geologic formations. Student B had also proposed quite a sophisticated research project, trying to marry the active fluid flux present in the hydrothermal systems with an understanding of geologic processes such as earthquakes and related movements associated with volcanic eruptions. During the two weeks at the ISC, this student worked closely with scientists to hone his research plan. The scientists were able to help him focus on how to determine the area of active hydrothermal activity in order to narrow the area of data collection, and he successfully managed this data collection when acting as watch leader. After the remote data-collection period at the ISC, he was able to complete an impressive amount of analysis. These examples should give some idea of the quality of student research and the changes in scope from initial ideas to final analyses.

All of the students exhibited considerable learning, not only of ocean science content, but also about multiple data gathering and analysis tools and about how to write scientific research questions and findings. One mentor wrote in a daily survey that she was 'trying to get them to make presentable professional papers, way beyond classroom standard.' Appendix 3 provides brief descriptions of the student analyses.

Uncertainty of field-based research

Some lessons students learned about conducting science research were mentioned multiple times in interviews and daily logs and can be summarised:

- Be flexible.
- Not everything is exciting – data analysis can be tedious.
- It is difficult to get a final product; there will likely be unexpected obstacles.

An important lesson these students learned about conducting research involved recognising that the data they collected during the cruise required a great deal of processing and analysis, and in some cases yielded no obvious results. Additionally, students experienced challenges of fieldwork (weather, currents) that they had not expected and had little control over. In interviews, the mentors indicated that they were more accustomed to the idea of assigning small projects where students could be assured of an outcome. For this project, mentors had limited familiarity with the site and could not predict the extent to which they would be able to collect useful data to satisfy the students' research needs. Therefore, the students, while collecting data alongside experienced researchers, learned first-hand the need to stay flexible about research plans and even to re-evaluate what research questions could be addressed. In some cases, they had to consider what they could say about incomplete data, what conclusions they could draw at different stages of research (perhaps because of incomplete analysis), and how to include lessons learned.

Discussion

Indications of student learning during TREET were observed in the advances students made in content understanding and research skills. We believe preparation in the early seminar was a factor in helping most of the students to engage quickly in project activities when they began participating in the telepresence-enabled deep-sea fieldwork, as soon as they had learned about the communications technology at the ISC. The daily intensity of living and working together and interacting with the scientists, engineers, and ROV pilots on the ship is likely what engendered strong group camaraderie and strong scientist–student mentorship, which began in the seminar and intensified during the cruise. This mentorship included scientists located in very different settings (on ship and on shore) and was enabled by telepresence. An important outcome is the overall productivity of the students. Two students presented their results at professional conferences, one student published an article, and three students went on a research ocean cruise following TREET. Three of the seven students either have begun or plan to continue the work in graduate school.

We submit that TREET demonstrates that engaging in remotely conducted ocean science research offers opportunities for effective learning. Many lessons still need to be learned about how best to plan for undergraduate students in an environment that is just beginning to figure out how to have them participate. Additional challenges that need investigating as telepresence becomes more available to teachers and students include: how best to prepare professors for this type of URO; how to integrate the students into the well-established culture of ocean science and prepare the scientists, ROV pilots, and engineers for the distant participants; and how to support student learning across distance and across areas of specialisation within the scientific team. Despite these challenges, the students in this pilot project were encouraged to define their own research, to engage actively in fieldwork and direct their own data collection, to flexibly revise their plans as needed, and to analyse real-world data. They succeeded in each aspect and gained a great deal of knowledge about the field sites and about the real-world practice of ocean science. Along the way, they developed self-confidence, research skills, and content knowledge.

Cohen (1998) predicted that partnerships between students and scientists would prove to be an exciting new force in science education and in science, and we believe this project is a demonstration of that. The students showed gains in many of the areas reported in Sadler et al. (2010), including knowledge of the research process, how to communicate with scientists, how to communicate results in publications and presentations, and how to engage in teamwork with their peers, mentors, and other scientists. Our results support earlier findings that UROs can be a valuable experience for students. As Frodeman (2003) has suggested for fieldwork in general, the remote fieldwork appeared to facilitate the acquisition of expert knowledge, especially of data collection and analysis procedures. The field experience also provided important opportunities for mentoring these students, consistent with Hoskins and Price (2001).

We expected that the students would be enthusiastic about playing an active role, but students also expressed great enthusiasm for witnessing the back-and-forth between scientists. Siemens (2014) has recently suggested that decision-making itself is an important learning process in the midst of sometimes overwhelming amounts of information, that 'learning is a process that occurs within nebulous environments of shifting core elements – not entirely under the control of the individual' (p. 7). It is possible that the strong student engagement with scientist–scientist exchanges was motivated by the fact that the scientists were solving unexpected problems and making moment-by-moment decisions in the field. TREET provided the undergraduates with unusual exposure to decision-making in a constantly altering 'information climate' (Siemens, 2014, p. 7). This appeared to make a strong impression on the students, who mentioned the discussions between scientists and the importance of flexibility multiple times in their surveys and interviews.

Even though the experience was enabled by telepresence, it was very unlike a VFT, which occurs in a pre-planned environment. Along with the experts, the students had to revise their own analysis plans and even their original research questions in light of the changing conditions in the field and the data they were able to collect. We submit that this constituted valuable experience about the practice of science in the real world not often available to undergraduate students, especially in deep-sea research.

Summary and conclusions

In TREET, telepresence-enabled research engaged students in learning many skills and concepts often associated with traditional UROs. In addition, scientists reported that students' remote interactions with shipboard scientists were similar to what typically happens with students on a ship. Students were able to undertake all aspects of research: design, hypothesis, fieldwork, data collection, analysis, and revision. They also had the opportunity to be 'scientist for a day,' directing the ROV during data collection for their own research needs. This is when we witnessed the promise of telepresence most fully realised – when students were directing data collection. Students learned challenging lessons about the way scientists conduct research, in general, and ocean science research, in particular, both while watching experts problem-solve in the field and in the course of conducting their own research. They learned of the need to stay flexible about research plans and even to re-evaluate what research questions can be addressed, as well as how to analyse and draw conclusions from the data that are actually obtained.

Because of these gains, we recommend that telepresence be considered an option for future undergraduate research experiences. It can be a reasonable approximation of an experience of fieldwork at sea, an experience normally out of the reach of undergraduate students. Telepresence promises to allow many more students to conduct remote research at places as fascinating and unreachable as the bottom of the ocean.

Notes

1. More broadly known as ROVs (Remotely Operated Vehicles).
2. Interview questions for the final student and mentor interviews are available in supplementary online materials (Tables S1 and S2).
3. For most of the cruise, students took part in round-the-clock shore-based watches. Researchers observed all daytime watches (7 a.m. to 7 p.m.) and most night watches (7 p.m. to 7 a.m.).

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References

Ballard, R. D., & Durbin, M. J. (2008). Long-term preservation and telepresence visitation of cultural sites beneath the sea. In R. D. Ballard (Eds.), *Archaeological oceanography*. Princeton, NJ: Princeton University Press.

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

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

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

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

Cohen, K. C. (Ed.) (1997). *Internet links for science education: Student scientist partnerships*. New York, NY: Plenum.

Cohen, K. C. (1998). Introduction to the issue. *Journal of Science Education and Technology*, *7*(1), 1.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, *23*(7), 5–12.

Fowler, C. J. H., & Mayes, T. (1997). Applying telepresence to education. *BT Technology Journal*, *15*(4), 188–195.
Frodeman, R. (2003). *Geo-logic: Breaking ground between philosophy and the earth sciences*. Albany: State University of New York Press.
Fuller, I., Edmondson, S., France, D., Higgitt, D., & Ratinen, I. (2006). International perspectives on the effectiveness of geography fieldwork for learning. *Journal of Geography in Higher Education*, *30*(1), 89–101.
Garner, L. C., & Gallo, M. A. (2005). Field trips and their effect on student achievement and attitudes: A comparison of physical versus virtual field trips to the Indian River Lagoon. *Journal of College Science Teaching*, *34*(5), 14–17.
von Glasersfeld, E. (1989). Cognition, construction of knowledge, and teaching. *Synthese*, *80*(1), 121–140.
Gonzales, D., & Semken, S. (2006). Integrating undergraduate education and scientific discovery through field research in igneous petrology. *Journal of Geoscience Education*, *54*(2), 133–142.
Hoskins, D. M., & Price, J. G. (2001). Mentoring future mappers. *Geotimes*, *46*(6), 11.
Jonassen, D., Davidson, M., Collins, M., Campbell, J., & Haag, B. B. (1995). Constructivism and computer-mediated communication in distance education. *American Journal of Distance Education*, *9*(2), 7–26.
Kintisch, E. (2013). A sea change for U.S. oceanography. *Science*, *339*, 1138–1143.
Lock, R. (1998). Fieldwork in the life sciences. *International Journal of Science Education*, *20*, 633–642.
Lopatto, D. (2004). Survey of Undergraduate Research Experiences (SURE): First findings. *Cell Biology Education*, *3*, 270–277.
Minsky, M. (1980, June). Telepresence. *OMNI Magazine*, *2*(9), 44. Retrieved from http://web.media.mit.edu/~minsky/papers/Telepresence.html
Nagda, B. A., Gregerman, S. R., Jonides, J., von Hippel, W., & Lerner, J. S. (1998). Undergraduate student-faculty research partnerships affect student retention. *Review of Higher Education*, *22*, 55–72.
Pallant, A., McIntyre, C., & Stephens, L. (2016). Transforming undergraduate research opportunities using telepresence. *Journal of Geoscience Education*, *64*(2), 138–146.
Russell, S. H. (2006). *Evaluation of NSF support for undergraduate research opportunities (draft synthesis report)*. Arlington, VA: SRI International.
Russell, S. H., Ailes, C. P., Hancock, M. P., McCullough, J., Roessner, J. D., & Storey, C. (2004). *Evaluation of NSF support for undergraduate research opportunities (draft executive summary)*. Arlington, VA: SRI International.
Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of undergraduate research experiences. *Science*, *316*, 548–549.
Sadler, T., Burgin, S., McKinney, L., & Ponjuan, L. (2010). Learning science through research apprenticeships: A critical review of the literature. *Journal of Research in Science Teaching*, *47*(3), 235–256.
Siemens, G. (2014). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning*, *2*(1), 3–10.
Singer, S. R., Nielsen, N. R., & Schweingruber, H. A. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. Washington, DC: The National Academies.
Spicer, J. I., & Stratford, J. (2001). Student perceptions of a virtual field trip to replace a real field trip. *Journal of Computer Assisted Learning*, *17*(4), 345–354.
Wagner, J. K., McEntee, M. H., Brothers, L. L., German, C. R., Kaiser, C. L., Yoerger, D. R., & Van Dover, C. L. (2013). Cold-seep habitat mapping: High-resolution spatial characterization of the Blake Ridge Diapir seep field. *Deep Sea Research Part II: Topical Studies in Oceanography*, *92*, 183–188.

Appendix 1. Examples of observation categories identified for each data source

Table A1. Examples of observation categories.

Source	Descriptors for categories
Daily surveys: 10 scientists (49 surveys; from 3 to 9 per scientist)	Students engaged, dedicated Students are bored, passive, need to be more engaged **Students contributing to the scientific work** **Student questions similar to those of students on ships** **Students have gained in skills and confidence**
Daily surveys: 7 students (71 surveys; from 7 to 13 per student)	**Observed science in action** Not much happening/didn't do much **Scientific collaboration with Inner Space Center or other scientist** Felt satisfactorily supported Want to go on a cruise, would be cool to be on a ship
End-of-cruise interviews: Scientist $n = 9$	On ship, you can learn by watching Not enough feedback cycle for student projects during planning phase **Students needed to learn/did learn that there is flexibility to change plans at sea** **Observed changes in students**
End-of-cruise interviews: Student $n = 7$	**Telepresence worked well/very well** **Working with or talking to other scientists was cool** **Next best thing to being on a ship** Would not have gotten opportunity to work on such a project otherwise **Be prepared for your plans to be volatile** Communication challenges w ship
Observation logs (Authors' logs for daytime and nighttime shift observations)	Senior personnel directly mentoring students Students bored or don't have much to do Students data logging or on communications Students initiate interaction with scientists **Students take initiative with some aspect of the research** Ship to shore communications issues (other than technical) Ship to shore communications involve the students beyond the Sci Chat
Follow-up student *nterviews* $n = 6$	**Research plans changed a little or a lot** Challenges of planning and collecting data remotely Challenges with obtaining data after cruise
Follow-up mentor *nterviews* $n = 3$	**Students collaborated with other scientists** Students received data too late to analyse sufficiently **Students learned about science process** **Students learned about science content**
Student presentations $n = 7$	**See headers in the table in Appendix 2**

Notes: Bolded categories relate to student learning and informed this paper. Other observation categories informed a related paper (Pallant et al. 2016).

Appendix 2. Characterising the growth/change exhibited by student presentations

Table A2. Grid used to help characterise growth/change in each student project, as reflected in the student presentations.

Student 1 presentations	Question	Significance	Thesis	Data collection and backup methods	Analysis plan and backup analysis plan	Instruments	Drawbacks/ Questions	Outcomes	Feedback from mentors & other scientists
Apr 2014									
Oct 2014									
Apr 2015									
Author 1 notes: describe growth/ change									
Author 2 notes: describe growth/ change									

Notes: The headings are elements in the student presentations. Once a grid was created for each student using student-created presentation slides and summaries along with videotape transcripts, two of the authors independently created descriptions of growth and change by comparing individual elements in the student's earlier and later presentations. Because of differences in how students thought about their projects at each stage (before, during, and after the two-week remote fieldwork experience), the language they used and the issues they found relevant also changed. Therefore, not every cell in the grid was filled for every presentation. We did not attempt to characterise every change, but focused on changes in knowledge of both science content and science practice as it related to that student's project.

Appendix 3. Summaries of the results of student analyses

Student A asked about the different lithology and facies that make up the debris avalanche. Data collected were video of the debris avalanche, photographs that were assembled into a photomosaic, and vertical transects of the avalanche. The student created geo-referenced photos on a map along the Kick 'em Jenny avalanche and identified a carbonate outcrop, a volcanic contact area, and columnar jointing.

Student B planned to characterise the hydrothermal circulation around the Kick 'em Jenny saddle area. Data collected were photomosaics, sub-bottom profiles, and laser line scan data. The student analysed the photomosaics, began sub-bottom data analysis, and compared bacterial mats as a proxy to show differences in circulation.

Student C asked how biodiversity varies at the cold seeps from site to site. Data collected were photomosaics and bathymetry maps. This student presented the status of work completed, but did not complete analysis.

Student D asked how the composition, rate, and distribution of fluid flows at the Barbados mud seeps vary. The student was unable to find fluid flow, but did capture bubble video-imaging at several sites. However, the bubble flow analysis was inconclusive.

Students E and F initially worked together, and asked whether bathymetry would show changes between the current year and previous year. Bathymetric data were collected but were not received before the end of the semester. The following semester, Student E's schedule precluded his continued participation. Student F then teamed up with Student G.

Student G asked about the spatial distribution of geologic features in and around the Kick 'em Jenny volcano. Photos for mosaics were collected. Student G teamed up with Student F to complete analysis.

Students F and G presented a revised, combined plan. They analysed the photomosaics and characterised surface features by colour and texture to show the spatial distribution of those features. They also presented a detailed plan to overlay the 2D photomosaics with the 3D bathymetry map and event log data to create a complete map of the data gathered during the cruise.