INSPIRE Track 1: Transforming Remotely-conducted Research through Ethnography, Education & Rapidly Evolving Technologies (TREET).

1. Introduction

This project seeks to make important inroads into the mechanisms by which remote human-robotic interactions can be utilized to transform the future of research and how these same systems can be leveraged to advance the research experiences of early career scientists and students. In parallel, the importance of the role of the oceans in regulating climate change is being increasingly recognised across the broader reaches of society (both the general public and decision-makers alike). This makes the parallel domain-specific goal of this project, to improve wider engagement with the remote deep-ocean, ever more timely – indeed, urgent.

In this project, therefore, we propose a bold approach: we will draw upon our orthogonally-intersecting expertise in ethnography, education and technology to pursue telepresence-focused investigations in the context of a nested oceanographic research project (that will rely upon telepresence technologies) to investigate the sources and fates of important greenhouse gases released to the deep ocean from beneath the sea-floor (Fig.1). Our ocean sciences program will be led by an innovative team of early career scientists who are pioneering the use of *in situ* sensors that can be deployed from advanced robotic systems. What will be particularly innovative about this project, therefore, is that while the area to be investigated lies in the SE Caribbean, the entire research team will conduct their program from shore, via the Inner Space Center (ISC) in Rhode Island. Engineers to support critical robotic vehicles and sensors will be stationed aboard ship for this "Tele-Cruise" but all scientific observations, data analysis and decision making for vehicle missions will be made at the ISC. Further, taking full advantage of this shore-based approach, we will also include 12 undergraduate students from across the continental US in all phases of the project: developing the research program in Y1; participating in the "virtual cruise" at the ISC at the outset of Y2 and completing their own research projects using data from the cruise throughout the rest of Y2. It is through this approach - working with and observing the team as they conduct their research - that we will seek to discern how research and education methods should evolve for next-generation scientists and educators. We consider this project to be both timely and essential: while the capability to provide remote and open access to large volumes of data is fast becoming routine, the mechanisms and work-practices to take full advantage of these developments are not nearly so mature.

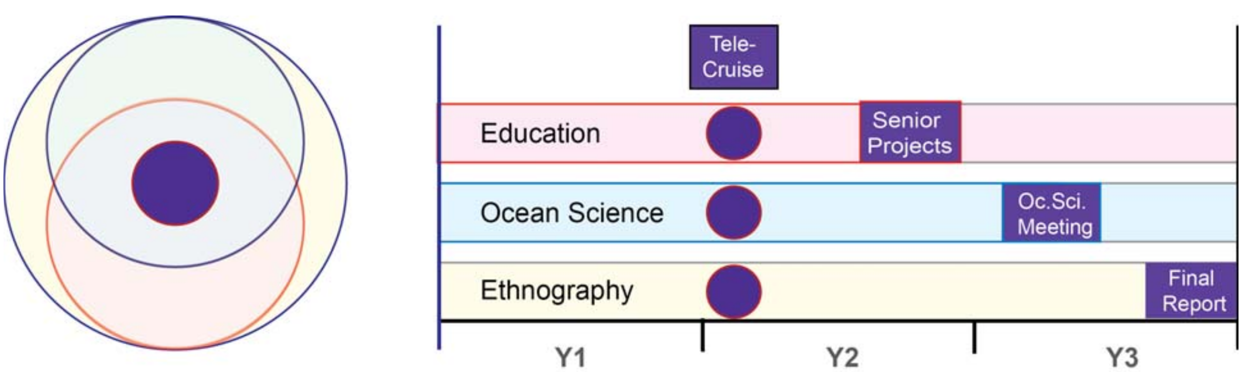

Fig.1 Left: Conceptual INSPIRE overview. A telepresence-enabled research cruise lies at the core of our intersecting scientific and educational research goals with ethnography pervading the whole.
Right: Timeline. Our three year INSPIRE program will also provide nested Educational (Y1-Y2) and Oceanographic (Y1-Y3) opportunities for a team of undergraduate students and early career researchers.

The advantages arising from our chosen approach are three-fold:

(i) The working environment is both extreme and remote: methodologies developed for this project will be mappable, directly, to many other fields of Earth and Space-based research.

(ii) The compelling nature of the research has attracted an extremely high calibre of enthusiastic early-career scientists, eager to participate in the project.

(iii) The project allows us to bring meaningful research experiences to a field of study where the direct participation of undergraduate students (aboard deep-ocean research vessels) has traditionally proved particularly challenging.

Working within our highly inter-disciplinary team will allow us to articulate an approach to transformative education that empowers students in the scientific process as it occurs. We will evaluate how the data-to-knowledge conversion is transformed through computational methods and how those methods can be used better to entrain young researchers. From this study, we will be able to determine future requirements to advance research in the context of a changing climate and evaluate how advanced computational methods in such diverse fields as Artificial Intelligence, Machine Learning and Spatial Statistics can play a significant role in educating the next generation of thought leaders in Science, Technology, Engineering and Mathematics.

2. Background

2a. What is telepresence?

In its simplest form, the term "Telepresence" (a phrase first coined by Minsky,1980) refers to a suite of technologies that allow an individual to perceive that they are present, or give the appearance of being present, or to have an effect at a location other than their own. Thus, telepresence requires that users' senses are suitably stimulated to give the feeling of being in that other location. Additionally, users may be provided with an ability to affect that remote location. To achieve this, any one or more of the user's movements, actions or voice may be sensed and transmitted to the remote location such that information may be traveling in two directions between the user and the remote location. In the context of this proposal, telepresence represents an innovative approach, allowing us to lead and implement scientific investigations from afar: compressing the physical distance and time of participatory exploration, with resultant disruptive methods in data gathering and analysis. This is transformative. Telepresence not only provides scientists with new tools and methods but, with its emphasis on advanced methods in computation science, has allowed new engineering approaches to be implemented "in the real world" that were hitherto confined exclusively to Computer Science research laboratories.

2.b) Telepresence in the oceans

The first telepresence-enabled expedition, pioneered by Dr. Robert Ballard, took place in 1989 when the JASON Project connected thousands of middle school students with scientists and engineers in the Mediterranean Sea through live interactions. The JASON Project continued to conduct annual educational expeditions, and in 2005 it partnered with NOAA's Office of Ocean Exploration, the University of Washington, the University of Rhode Island, Institute for Exploration, and Immersion Presents to conduct the first telepresence-enabled scientific expedition - to the Lost City hydrothermal field. Led by Drs. Deb. Kelley (at an Exploration Command Center at the University of Washington) and Ballard (aboard NOAA Ship *Ronald H. Brown)*, shore-based scientists stood watches directing the operations of two Remotely Operated Vehicles piloted by engineers at sea to accomplish their research objectives.
Since then, both NOAA's Office of Ocean Exploration and the Ocean Exploration Trust have been working to develop improved telepresence capabilities – most recently aboard two

dedicated vessels that both came online in 2009: the *Okeanos Explorer* and the Exploration Vessel (EV)*Nautilus*. In parallel, the Inner Space Center (ISC) at the University of Rhode Island, the hub for most current shore-based telepresence activity, also opened in 2009 with smaller Expedition Command Centers (ECCs) supported at other universities and research institutions worldwide. Both *Okeanos Explorer* and *Nautilus* continue to use the ISC for technical, scientific, and educational support during expeditions, but have evolved subtly different operating modes: *Okeanos* has 3 science berths and relies heavily on shore-based scientists using tools developed for data sharing and real-time collaboration while *Nautilus* has space for a larger science team at sea and calls on experts ashore when required. To-date both organizations have primarily used remotely operated vehicles (ROVs) to broadcast live from the seafloor, but *Okeanos* recently partnered with NSF to pioneer telepresence-enabled autonomous underwater vehicle (AUV) research (Brothers et al. 2013; Wagner et al., 2013).

2.c) The Educational Context

Importantly, this project will engage a significant number of undergraduate students in a program of deep-ocean research. (In conventional deep-ocean programs, science berths are so few that opportunities to engage undergraduate-level students rarely arise). Further, students participating in this research will need less emphasis on learning how to *obtain* data (through field observations and experiments) and more emphasis on learning how to *think* about those data and use tools to extract information from datasets. We anticipate that this will lead to a richer, more interesting learning experience such that the educational gains are likely to be at least as strong as those in other Research Experiences for Undergraduates (REU) programs with a distinct shift: from generating data to thinking about the research. Studies of other undergraduate research experience programs have shown that both the student and the research community benefit from student participation (Nagda, et. al, 1998). Students show gains in understanding the research process, communication, technical and computer skills, teamwork, working independently, information retrieval, understanding primary literature, scientific ethics, and statistical skills (Bauer & Bennett, 2003; Lopatto, 2004; Sadler et al., 2010) as well as a higher likelihood to pursue STEM-related careers (Russell et al., 2007). In addition to REUs, there are also numerous informal approaches to engaging students in scientific research. Some, such as the GLOBE project (www.globe.gov) which is most closely aligned with this project's subject matter are designed to be educational. Fewer projects, however, allow students to engage in all aspects of the research, as proposed here, and those that do have proved difficult to sustain because the benefit is rather one-way; researchers donate their time but seldom gain useful scientific results in return. External research on the educational value of projects that crowd-source data or allow students to undertake their own studies are few and either lack hard data or are equivocal (Means, et al, 2000). By contrast, the REU approach is well established with over 1,000 NSF-funded projects that offer research participation (Russell et al., 2007). This large-scale, long-term adoption of REUs is, no doubt, due to its proven educational value *and* ability to provide research results to scientists.

3. Project Partnership and Structure

This project involves three categories of researcher: the INSPIRE PIs; the Early Career ocean scientists (and their undergraduate students); and two experienced Expert Mentors who have agreed to join the program to share both their extensive oceanographic experience in the field areas to be investigated (essential during Y1 development of the research program) and their prior experiences as pioneers in the use of telepresence for their research. Only the INSPIRE PIs team will be funded directly by this proposal, although we have also included all participation costs for our early career, student and mentor partners in this telepresence-enabled project.

INSPIRE Principal Investigators: The diverse PIs brought together for this proposal are all experts in their fields. PI Chris ***German*** is a senior scientist at the Woods Hole Oceanographic Institution (WHOI) with expertise in the geologic controls of fluid flow from the deep ocean floor and their impacts on global scale ocean budgets. As well as having directly relevant experience coordinating complex multi-disciplinary & international collaborations (including leadership roles with *InterRidge* and *Census of Marine Life*), he currently serves as WHOI's Chief Scientist for Deep Submergence, leaving him well-placed to appreciate both the ever-evolving needs of the US ocean research community and the emerging capabilities offered by cutting-edge technology. Co-PI Katy Croff ***Bell*** has complementary ocean-based expertise. As Vice President of the Ocean Exploration Trust (OET) she has played a pioneering role over the past decade in developing the use of telepresence technology to conduct deep ocean exploration, outreach and K-12 educational programs. Co-PI Amy ***Pallant*** has led the curriculum development and educational research on several NSF-funded projects at the Concord Consortium (CC), a not-for-profit organization committed to bringing technology's promise into reality for education. Her particular expertise is in developing curricula in Earth System science. At the Harvard Kennedy School (HKS), Co-PI Sheila ***Jasanoff*** is Director of the Science, Technology and Society Program where her research interests include comparative studies of scientific and technological innovation across institutions and communities. HKS post-doctoral fellow Zara ***Mirmalek,*** with past experience at NASA and MIT, has specific expertise in human-machine relationships and how they affect knowledge production. Her doctoral research included a study of people, processes and technologies on NASA's Mars Exploration Rovers mission. It was through contributing her ethnographic approach to that project that Mirmalek first collaborated with Co-PI, Kanna ***Rajan***. Previously a Program Manager for Autonomy and Robotics at the NASA Ames Research Center, where he specialized in Human/Robotic collaboration, Rajan is now Principal Researcher for Autonomy at the Monterey Bay Aquarium Research Institute (MBARI) where he continues to pursue developments in Marine Robotics & Artificial Intelligence.

Early Career Scientists: For this proposal we have been able to establish an excellent team of innovative early career ocean scientists - drawn from across the continental US - who are fully supportive of the larger project and are committed to working with us, both to pursue our INSPIRE goals *and* to take advantage of the opportunities presented to conduct their own highly innovative research, including mentoring their students' research work. Our team of early career scientists comprises: 1) Dr.Eric ***Mittelstaedt*** (University of Idaho); 2) Dr.Masako ***Tominaga*** (Michigan State University); 3) Dr.Chris ***Roman*** (University of Rhode Island); 4) Dr.Anna ***Michel*** (WHOI); 5) Dr.Scott ***Wankel*** (WHOI) and 6) Dr.Peter ***Girguis*** (Harvard). Together, this team spans expertise across the Earth, Ocean and Life Sciences with a common bent that all are pioneers in the use of *in situ* sensing for their innovative deep ocean research. Thus, both they and their students will be particularly well-placed to extract maximum advantage from the innovative telepresence-enabled approach that we will employ.

Expert Mentors: To maximize the chances for progress in our ocean-based research, our team is further augmented with two senior "science-mentors". Prof. Steve **Carey** (URI) is a physical volcanologist with past and on-going experience as Chief Scientist for four telepresence-using cruises aboard the EV *Nautilus*, two of them to one of our key study sites: Kick'Em Jenny seamount. Prof. Cindy **Van Dover** (Director, Duke University Marine Lab.) has complementary expertise in the biology and biogeography of chemosynthetic ecosystems including a particular interest in understanding gene-flow between adjacent cold-seep and hydrothermal vent ecosystems. Her two most recent projects, in 2012, were to lead ROV *Jason* dives to cold seep sites on the Barbados Mud Volcanoes (our other key study area for the work proposed here), and as Chief Scientist for a pioneering program to Blake Ridge and Cape Fear cold-seep sites. The latter represented the first ever telepresence-enabled cruise to use a deep-ocean AUV.

4. Proposed Work

4.a) Overview

This project comprises an oceanographic research program nested within an ethnographic and educational research study designed to enable an informed view of emergent needs in computational science, investigate transformative ways to conduct research remotely and, simultaneously, provide students with active participation in the research as it is conducted at that remote location and discern how better to make use of telepresence for education into the future. At one level, a core team of leading early career scientists and their students – overseen by mentors with directly-relevant experience and expertise - will be engaged in compelling, cutting edge research investigating the geological controls, flux and biogeochemical fate of the greenhouse gases methane and CO_2, as they are released to the oceans from the seafloor. Rather than conducting their research in a conventional expeditionary manner aboard a research ship, however, this team will make extensive use of the Inner Space Center in Narragansett, Rhode Island as their hub. From there, they will be connected, via telepresence, to the EV *Nautilus* and the advanced robotic systems they will use: ROV *Hercules* and AUV *Sentry*.

In parallel, and at a higher level, our team will work to develop new collaborative tools and work-practices for remote research and learning that will be tested and evaluated in partnership with these early career ocean scientists, their students and their mentors. To start the cruise the entire team will work together at the Inner Space Center to establish both work practices and a camaraderie most closely comparable to that experienced at sea; during a later stage of the cruise, however, a subset of the team will be relocated to a smaller more remote command center at WHOI, approximately 70 miles distant. The latter more closely resembles a potential future approach with multiple distributed command centers throughout the US. We consider this last component particularly important, therefore, to allow us to investigate what further complexities, if any, such added separation might cause. Our efforts will seek to facilitate the research effort through three phases, each of which will make extensive use of telepresence:

Year 1:

- familiarization, including student education, with the technologies to be utilized, the research environment to be studied and the goals of our larger INSPIRE program;
- development of specific research programs (early career scientists & students);
- development of a coherent cruise program for the Year 2 virtual cruise to the Barbados Mud Volcanoes and Kick'Em Jenny seamount.

Year 2:

- implementation of the research cruise, including near-real-time, large-volume, data-sharing and processing to enable timely, informed decision making and direct student participation in the research;
- open-access data sharing and publication of results, post-cruise;
- student-led on-line seminars & submission of abstracts to the 2016 American Geophysical Union and American Society for Limnology and Oceanography's Ocean Sciences meeting.

Year 3:

- In the final year of the project our primary goal will be to present our results at major international meetings and publidh them in the relevant peer-reviewed literature (ocean sciences, social sciences, educational research, computer sciences).
- Throughout the program, the INSPIRE PIs will conduct a thorough evaluation of the tools and work-practices that we develop but an important goal in Y3 will be to draw together recommendations on the best way forward to prepare for the new paradigm of data-intensive, open-access science and present them to NSF and other interested parties.

This is important because our work will not just be relevant to the **Ocean Sciences**, which represents just one discipline where a compelling need to improve the use of telepresence has already been identified and the advances to be gained would be transformative. Rather, we anticipate that this project would also provide an important first step leading to new endeavors in **Computer and Information Science** and **Educational Research** that will be widely applicable across multiple fields of research and education. (See, also, *Section 6: Broader Impacts*).

4.b) Sources & Fates of Greenhouse Gases released from the Deep Ocean floor.

Much recent attention has focused on the potential for future release of methane direct to the atmosphere from shallow submarine gas hydrate fields, for example those on the Eastern Siberian continental shelf (Shakhova et al., 2005; Shakhova & Semiletov, 2007). The majority of global methane release from the seabed, however, occurs much deeper, along active and passive ocean boundaries where the fate of that methane, and associated CO_2, is poorly understood. In this project an inter-disciplinary team of early career scientists will conduct nested scale (over 6 orders of magnitude, 10s of km to 10s of mm) investigations, using advanced mapping, computational, and modelling approaches, to study the fluxes and fate of greenhouse gases released from the seabed. This work will be focused on the active plate boundary in the SE Caribbean, where numerous mud volcanoes and an active submarine arc-volcano are juxtaposed (Fig.2). The region is dominated by subduction of the North American plate beneath the Caribbean plate giving rise to the Lesser Antilles Arc volcanic system in the West, the deep ocean trench to the East and, in between, the Barbados Accretionary Prism.

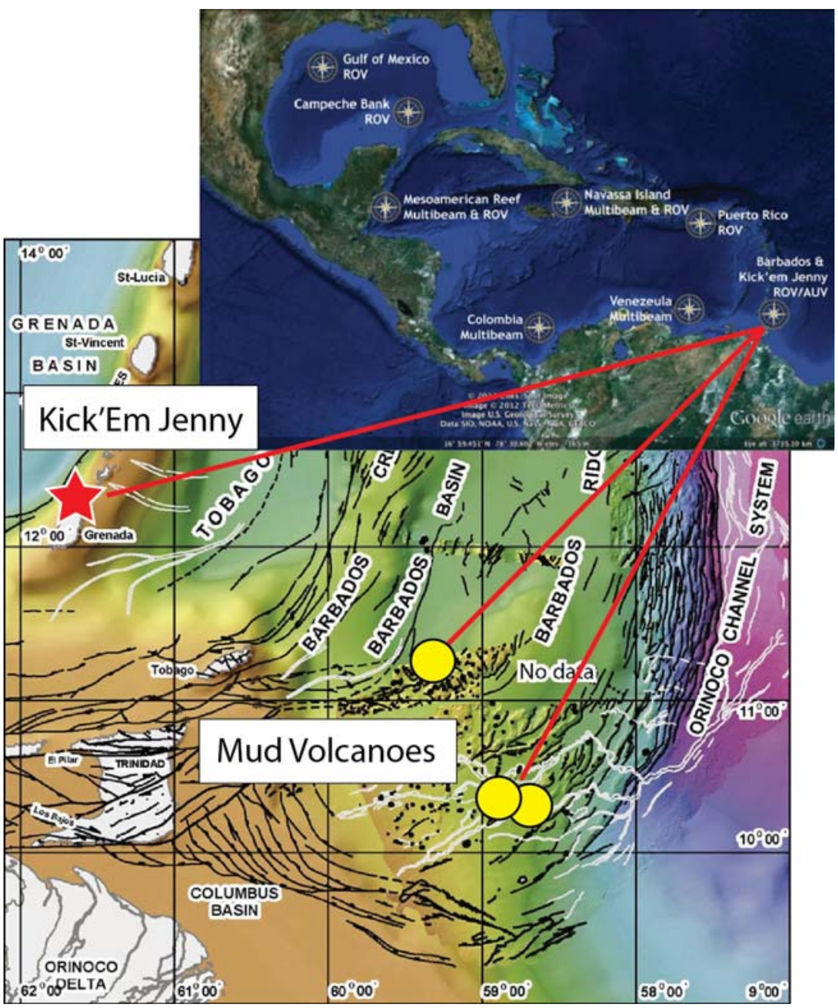

Fig.2 *Map (after Deville et al., 2006) showing field area in the SE Caribbean including Kick'Em Jenny (red star) and the Barbados Mud Volcanoes which host at least 3 cold-seep sites (yellow circles). Inset: location of the study area in the context of the larger 2014* EV *Nautilus Program for the Caribbean Sea.*

While mud volcanoes are common along a variety of ocean margins, the Barbados Mud Volcano (BMV) field is particularly well developed. Geologically, these systems develop from the upwelling of fluids from deep beneath the seafloor that carry water, gas and particles of sedimentary material up to the seafloor where, over time, successive layers of outflow can build up conical mounds reminiscent of volcanoes and up to 1km in diameter (Deville et al., 2006). In many cases, these systems are also associated with transient, anomalously high heat-flow when compared to background and the fluids are typically enriched in methane, believed to be thermogenic in origin, leading to the development of chemosynthetic ecosystems dominated by vesicomyid clams and bathymodiolus mussels at depths ranging from 1000-5000m in depth (Jollivet et al., 1990; Olu et al., 1996, 1997). While the precise program to be followed will only be refined over the course of Y1, examples of studies that our early career scientists have each indicated that they would be interested in pursuing, in their individual letters of support for this project (see *Supplementary Documentation*) include: ROV surveys to study the distribution and coupling of microbial-geochemical processes and megafaunal distributions; quantifying distinct sources of methane through isotopic composition analyses; surveying the extent of microbially-catalyzed methane oxidation; and quantifying cold seep fluxes at the mud volcanoes. Parallel AUV-based studies would characterize known seep sites through a combination of high resolution near-bottom bathymetry, sidescan sonar and chirp (sub-seafloor) surveys, while systematic photographic surveys would allow dominant fauna to be identified and ecosystem structures to be quantified (Brothers et al., 2013; Wagner et al., 2013). Using coordinated AUV and ROV observations the team would be able to quantify local fluxes and extrapolate to regional-scale fluxes of these greenhouse gases.

West of the BMV, Kick'em Jenny (KEJ) is the most active and dangerous submarine volcano in the Caribbean (Devine & Sigurdsson, 1995). During the past century it has shown a history of progressive growth with explosive eruptions that pose hazards to local island populations in the Lesser Antilles (Dondin et al., 2012). Specific hazards include explosive eruptions that can breach the sea surface and the potential for tsunami generation from shallow water explosions or edifice collapse (Lindsay et al., 2005). Kick'em Jenny is located on the western flank of the Lesser Antilles arc, just offshore from the island of Grenada (Fig. 2) and was discovered in 1939 when numerous earthquakes were felt and tsunamis affected Grenada, the Grenadines and Barbados. An explosive eruption broke the surface, producing ash-columns that reached up to 300m above the sea surface (Devas, 1974). There have been at least eleven eruptions since that event with the most recent in 2001. The first detailed survey of the volcano in 1972 revealed a 1300m high conical structure, constructed on the western flank of the arc. The summit crater was found to be at a depth of 190 m and approximately 180 m in diameter. Two prominent 70-150m high west-facing scarps east of the volcano were identified as north-trending normal faults, defining the shelf break of the arc's west flank. These are likely related to a major edifice collapse of a larger pre-existing volcano surrounding the current KEJ cone.

Prior work along the Lesser Antilles arc identified that KEJ emits strong hydrothermal signals (Halbach et al., 2002; Koschinsky et al. 2007). ROV surveys of the crater floor in 2003, soon after the 2001 eruption, found high temperature venting of fluids (>250°C) and gases, along with the discovery of new species of vent-endemic worms (Wishner et al., 2005). Venting of fluids occurred within a small sediment-filled depression nested within the main crater of the volcano. The nature of the gas being discharged was not sampled at that time but is likely to be rich in carbon dioxide ± methane as found in many other arc vent-systems (Lupton et al., 2008). With its shallow depth and close proximity to Grenada, KEJ provides an ideal location for a variety of interdisciplinary studies. Projects proposed to-date (see *Supplementary Documentation*) include investigating both 1) the shallow magmatic system and internal structure of the volcano and 2) the hydrothermal system hosted within the KEJ crater. Examination of the shallow magmatic system would be undertaken using a ROV-deployed muon spectrometer. This system is able to detect cosmic-ray produced muons that penetrate into the Earth's crust and reveal the internal structure of volcanic edifices. This technique has been applied previously to sub-aerial volcanoes but this would be the first such deployment in a submarine setting. The second area of research would be a focus on the KEJ hydrothermal systems with much overlap of interests between this work and the team's interests at the BMV cold seep sites. ROV observations from 2003 indicate that venting is distributed throughout the crater, in sedimented areas and along scree slopes, with sulphide mineralization located just beneath the seafloor.

The nature of this unfocussed venting (no distinct chimneys have been reported in the KEJ crater) lends itself well to the studies proposed: the *Sentry* AUV would be used to conduct high resolution bathymetric, sidescan sonar, near-bottom chirp sonar and 3-component magnetic surveys of the volcanic edifice and, where appropriate, down-looking photomosaics as well to constrain the geomorphology and major structures of the vent field and any chemosynthetic communities that they host (e.g. within the KEJ crater). A novel laser line-scanning system, coupled with HD imaging from the ROV would be used in two independent studies aimed at quantifying volume fluxes of hydrothermal fluids escaping from the seafloor and the relationship of that fluid discharge to major geological structures. Together with these flux estimates, determining the chemical composition of the gases being produced at Kick'Em Jenny will also provide an improved estimate of the chemical fluxes of methane and CO_2 from these regions at the larger scale – a major priority of the EV *Nautilus* based work. If carbon dioxide is the main gas being discharged then there may be significant local ocean acidification effects with potential impacts on the surrounding biological communities and ocean chemistry. As at the BMV seep sites, stereo cameras on the ROV will be used to characterize the microbial and biological communities present and investigate their structure in relation to fluid venting and geochemical signals, as determined from *in situ* biogeochemical sensors.

Fig.3 Interior of the Inner Space Center (ISC) as used by Dr Van Dover (left) for AUV dives in 2012.

4.c) Educational Research Program

Three prior research findings inform the design of the **educational program** we propose:

i) Student researchers' level of involvement correlates positively with their satisfaction and perception of gains. Students more fully immersed in a culture of science tend to report more positive perceptions (Campbell, 2002; Russell et al., 2007). "Immersed" was judged by participation in scientific conferences, authoring papers and mentoring less experienced student researchers.

ii) Duration of student research experiences is positively correlated with satisfaction and intentions to attend graduate school. REU experiences sustained over multiple semesters tend to demonstrate stronger outcomes than single summer programs.

iii) The quality of faculty mentoring is important. The most common response to Russell et al. (2007)'s open-ended survey question about how to improve the REU research experience was to increase the quantity and quality of faculty mentoring.

Our educational program will incorporate these lessons by planning to immerse students in research for the better part of two years and to provide extensive, quality faculty mentoring. Of our six early career research scientists, the four at Universities with active undergraduate programs (Idaho, Michigan State, URI & Harvard) will each mentor three undergraduate students from their institution. These 12 students will all be juniors at the start of the project and will have declared that they are science majors.

These students will all be recruited during Fall 2013 to coincide with the start of Year 1 of our proposed project. All participants will enrol in a semester-long credit-bearing online seminar series offered between January and May 2014. The seminar will be designed to introduce the project and provide students with background they will need to undertake the Year 2 research. At the outset, this set of seminars will cover background Earth and Life Sciences research pertinent to the sites to be studied, more detailed case-studies of the unique features of the research sites to be investigated, the advanced robotic vehicles and the "big data" sharing and analysis tools to be employed as well as an overview of the broader INSPIRE project within which their own research is nested. The PIs of this proposal, together with the early-career scientists and expert mentors, will develop and deliver this online seminar series.

Singly or in small groups, undergraduates will then work with their respective early-career professors to define valid research questions, develop tractable research plans, and pursue that research with mentoring from the early career scientists. This will allow focus to change, toward the latter stages of the same seminar program, to more detailed cruise planning: seminars will be devoted to individual scientists and their teams so that they can each present their intended research questions and plans. Once this is completed, the team, collectively, will need to reach mutually-agreed priorities to ensure optimal outcomes for all the diverse research groups and their interests. To achieve this, the final seminar of the program will be a moderated cruise-planning discussion, joined by all partners and students, led by overall INSPIRE PI, German. Concord Consortium staff will coach presenters on best strategies for successful online seminars, and the entire seminar program will be archived for later analysis and potential re-use.

The cruise is scheduled for Fall 2014, at the start of Year 2 of our proposed project. While the cruise is underway, students will join the research program at the Inner Space Center where they will participate in daily operational decision making, data collection and interrogation, and mission planning. During and after the cruise, students will have access to all data collected on the cruise and will participate in post-cruise data analysis. Regularly scheduled post-cruise teleconferences will be planned for all participants throughout Fall 2014 to ensure that data are accessible, questions can be addressed about data analysis, research is discussed, and papers are reviewed. During the Spring semester of 2015, all student groups will present the results of their research to all other participants in the program using the same on-line seminar approach used in Year 1, prior to the cruise.

The goal of the **educational research** that we will conduct during the course of this project is to determine what students learned, whether the experience changed their career plans, their understandings of how telepresence can be used for research investigations, and to characterize ways in which this educational experience was unique and how it could be improved. The research will be designed to answer the following key questions:

Q1. What did the students learn about science and scientific research? Did students show gains in understanding of the research process, communication, technical and computer skills, teamwork, working independently, information retrieval, understanding primary literature, scientific ethics, and data mining skills? Were there changes in student understanding of the nature of scientific research?

Q2. Did the participants experience authentic research? To what degree did the students participate and contribute to the overall research? Did they formulate and pursue their own questions? Did the students make meaningful contributions to the research discussions and the decisions of what to observe and measure? Were they able to access necessary data and use appropriate analytical/ computational tools? Did they contribute to significant findings? To what extent did the students think that their experience represented authentic research?

Q3. ***In what ways did participation influence or change student career plans?*** Did they express increased interest in advanced study or STEM teaching? How do these findings compare to plans of similar students not in our TREET program?

Q4. In what ways did our TREET project differ from other REU programs? Were there differences in the time spent collecting and analyzing data and in the amount of time doing routine tasks? Were there differences in the nature and amount of communication with peers and scientists?

Q5. How could our TREET approach be improved further? How did students evaluate the seminar series, faculty mentoring, and the technology? What specific changes do students recommend?

The **educational research methods** employed during the course of this project will include surveys, interviews, and observations. The primary survey instrument will address research questions 1-3 and will be administered to participants on three separate occasions to track evolving trends: at the beginning of the program, just after the cruise, and at the end of the program. To be able to compare results with other findings, the bulk of the survey will be adapted from that described by Russell et al. (2007). In order to answer question four, each early career scientist will recruit three additional REU students and three non-REU majors with similar grades to constitute a comparison group. Each member of this group will also complete this survey at the same three times. To answer question five, participants will complete written evaluations at the end of the seminar and at the end of the project. During the cruise, a trained observer will be present at the research site(s). An observational protocol will be developed that focuses on the nature of the scientific activities of the students, the quality of the engagement of researchers with the students, and the topics that the students studied. To provide additional narrative data for all five questions, all project participants (i.e. project PIs, expert mentors and early career scientists) will be interviewed at the beginning and end of the project.

Fig.4 Example of a mini-Expedition Command Center already established at the Ocean Exploration Trust in Rhode Island. For our TREET project, an equivalent ECC - with the same core functional capabilities as the Inner Space Center - will be established at WHOI and utilized to investigate what differences arise in conducting remote telepresence-enabled research when working in a smaller more isolated group, as compared to the larger shore-based team operating from the ISC.

4.d) Ethnography Program

Our proposed ethnographic research seeks to:

i) ascertain and represent the work flow of remote telepresence, how it is different from ship-based science data collection, what is similar, what conflicts arise, and how these compare with related areas such as space exploration (Bresina et al., 2005; Mirmalek, 2008b);

ii) provide insights into the cultural processes shaping domain-specific human-machine relationships that inform technological solutions from Artificial Intelligence and Robotics which have had an impact in these disparate domains;

iii) help six early career ocean scientists and their undergraduates elucidate effective approaches to using remote telepresence in the conduct of their (deep ocean) research.

iv) support the development of education seminars for early career scientists and their undergraduate students as they use remote telepresence to conduct their (deep ocean) research.

Ethnography is the study of the practices through which a community makes meaning; the habits, values, social norms, assumptions, languages that members use explicitly and implicitly to make sense of their activities and to guide behavior and relationships (Geertz, 1973). These aspects constitute the culture of the community and are taught to its members both formally (i.e., through education and work) and informally (i.e., word of mouth; on the job; role model, "it's not in the books"). In conducting ethnography among specialized work communities, ethnographers seek to identify values, habits, formal and informal knowledge transfer processes, artifacts (e.g., information communication technology, interfaces, computational elements), language (e.g., disciplinary, colloquial), and habitual workarounds that inform members on how to do their work (Glaser & Strauss, 1967; Spradley, 1980; Trice, 1993). Ethnographic research can aid in developing new social and technical processes that will benefit the community being studied. Analysis of research data includes developing themes and identifying patterns in collaboration with community members and producing an interpretation of findings that can be wielded by collaborators.

The goal of the ethnography program proposed here is to study, record, and share analysis on the changes to long-standing habits of social interaction, information flow and access to and analysis of scientific data brought about through the use of remote telepresence. Studying work, social processes, and technological change in science communities using ethnographic methods is well grounded in the disciplines of: Science Technology Studies; Anthropology; Human-Computer Interaction; Communication; and Sociology (Bijker et.al., 1987; Clarke & Fujimura, 1992; Doing, 2009; Helmreich, 2009; Hutchins, 1995; Jasanoff, 2007; Jasanoff et al., 1995; Mukerji, 1990; Mutlu & Forlizzi, 2008; Traweek, 1988; Suchman, 2006; Vaughan, 1999; Woolgar et al., 1998). Our ethnographic research will offer insight into the new ways of doing work and new computational tool requirements that fall outside the environment in which traditional oceanography has developed (Ballard & Durbin, 2008; German, 2013).

Robotic assets (mobile and immobile) are being used increasingly for oceanographic investigations. Examples include Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), Autonomous Surface Vehicles (ASVs) and Unmanned Aerial Vehicles (UAVs) as well as cabled observatories such as those for NSF's Ocean Observatories Initiative (OOI). Consequently, there is substantial interest in exploring new modalities for oceanographic investigation: at and beneath the seafloor for marine geoscientists, from benthic to upper water-column communities for marine biologists, and throughout the ocean for biological, chemical and physical oceanographers. OOI, in particular, will engender the use of real-time data acquisition and analysis - especially in the context of cabled observatories. NOAA's *Okeanos Explorer* and OET's EV *Nautilus* were already designed to provide broadband

Internet connectivity from deep within the ocean interior and MBARI's NSF funded MARS observatory offers the scientific community a capability to observe the ocean at 900m on a 24/7 basis. With multiple AUVs, gliders and floats in the ocean and downloading data whenever they appear at the ocean surface, large volumes of data are now returned, routinely, from mobile assets. All these developments represent separate facets of the evolving field of oceanography that, in turn, have encouraged the paradigm of using near real-time data to make decisions during the course of experimentation as opposed to the *post-facto* analysis of gathered data which has been traditional throughout the history of ocean-based research.

These developments have changed the scientific process in the following ways:

- *i)* Increasingly, decision-making now occurs *within* and *during* the experimental process rather than *subsequent* to it.
- *ii)* Data gathering and analysis occurs at a substantially faster rate than before, leading to increased reliance on sophisticated computational methods. Younger oceanographers are increasingly knowledgeable and capable of using regression techniques for automated sampling, for instance (Graham et al., 2012).
- *iii)* Robotic assets are and have been re-tasked to deal with rapidly changing experimental goals. This in turn has resulted in opportunistic science (German et al., 2010; Ryan et al., 2010; Rajan et al., 2012).
- *iv)* Increased use of robotic methods has resulted in increased volumes of data gathering that, in turn, have increased the pace of experimentation and data return.

As a consequence, scientists whose working community did not previously use remote telepresence methods are now interested in developing the use of such tools, both for their own research and, increasingly, to achieve the longer term goal of sustaining their fields by attracting and retaining the next generation of researchers through K-12 STEM programs. In this project, our study group will involve a group of ocean scientists, with and without prior experience studying the oceans via telepresence, and at varying stages of their career and education, including our INSPIRE PIs German & Bell, six early career scientists and their undergraduate students, and our two Expert Mentors Carey and Van Dover. This range will allow us to consider how education, protocols, and new technologies for remote telepresence will resonate with established scientists, scientists who are seeking the “affordances” of telepresence (Norman, 2002), and upcoming scientists not yet acculturated towards a specific method.

Ethnographic studies of science and engineering workplaces are conducted to create robust accounts of social practices and technologies used in producing scientific discoveries and technology innovations. These accounts, known as “thick description,” provide insight into day-to-day work practices for science at the micro-level and in relation to political and institutional relationships, and historical backgrounds (Forsythe, 2001; Hughes et al.,1994; Kling & Star, 1998; Kunda, 1992; Mirmalek, 2008a; Star, 1999; Suchman, 2006; Traweek, 1988). Ethnographic research can contribute findings that reflect, in part, cultural norms, language and perspectives, an important consideration for the development and adoption of new technologies and organizational support of scientific discovery (Forsythe, 2001; Suchman, 2006; Tyre et al., 1991; Wales et al., 2002; Vaughan, 1999). For example, ethnographic research on NASA’s Mars Exploration Rovers (MER) mission was used to develop a naming convention and ontology, a prioritization scheme, and intent fields for the development of activity plans for tele-robotic science (Wales et al., 2007). Research among AI communities (Forsythe, 2001) evidences the need to incorporate cultural considerations of developers and users in the construction of expert systems which, without this insight, result in technological failures categorized as “user error”. Further, ethnographic research of large disasters such as NASA’s *Challenger* shuttle disaster show the significant influence that organizational processes of social interaction, information communication technologies, work flow, and work community-specific habits have on the production of scientific knowledge (Vaughan, 1999) and contribute to failure (Vaughan, 1996).

Ethnographic research requires the researcher to be 'situated' (Haraway, 1988) in the work-environment to be investigated, in order to participate first-hand in the community of study. As an "authorized" outsider with insider access, the researcher is able to participate and observe work across hierarchical roles and information flows, trajectories that are often difficult for community members to freely navigate. Mirmalek, the proposed postdoctoral fellow for this project, is an experienced ethnographer who, previously, was given full membership on NASA's MER mission to conduct research on the Athena Science team and Science Operations Support Team (Mirmalek, 2008a,b) – a study that enabled science and technology information and developments to be followed across workgroups and the multiple interpretations particular to the workgroup and their role in the process to be gathered. Mirmalek's research, in collaboration with the Work System Design & Evaluation, Human-Centered Computing group at NASA Ames, contributed to the enhancement of the tele-robotic scientific process and related mission surface operations, the design of computer technologies for AI-based planning, collaboration, and information exchange (Wales et al., 2007) which involved co-PI Rajan. Her experience with telepresence and exploration, along with that of co-PI Rajan, will assist ocean scientists in identifying areas to address, to prepare, and even to pioneer remote telepresence for future ocean research much as it informed the design and development of tools for the mission critical uplink process on MER (Bresina et al., 2005).

To achieve our proposed work, the ethnographer (Mirmalek) will maintain a sustained presence at the primary sites of study, at WHOI and at URI's Narragansett Bay Campus. At WHOI she will be able to interact with PI German, with other ocean scientists and with engineers from the National Deep Submergence Facility. In Rhode Island she will be able to interact with key members of both the Ocean Exploration Trust and NOAA's Ocean Exploration program (see Supplementary Documentation for Letter of Support) both of which are housed in the same building as the Inner Space Center (ISC)). Mirmalek will also observe and participate in two telepresence-enabled research cruises during the program. In Year 1, she will participate *in situ* on-board EV *Nautilus* during one cruise - possibly expert mentor Carey's already scheduled cruise to Kick'Em Jenny in October-November 2013. In Year 2, she will participate *in situ* on shore at the Inner Space Center and at the smaller, more remote Expedition Command Center at WHOI for the field program to the Barbados Mud Volcanoes and Kick'Em Jenny. During both expeditions she will: collect field-notes of work flow; conduct interviews (scientists, engineers, administrators involved in ocean science, telepresence support and development; using names provided by PI German, co-PIs Bell, Jasanoff, Pallant, and early-career scientists); and circulate notes and analysis for collaborative aims with the project's Education, Ocean Science and Computer Science partners (see HKS budget narrative for details).

5. Results of Prior NSF-funded research

5.a) C.R.German (Woods Hole Oceanographic Institution)

Award: C.R.German & J.Seewald; OCE-1061863; 09/15/11-08/31/13; $302,011.
Title: Venting Outside the Box – Extending the known limits to seafloor hydrothermal circulation & the chemosynthetic life it supports.
Intellectual Merit: This project has used the *Jason* ROV to map and sample two new vent fields on the ultra-slow spreading Mid Cayman Rise. The Von Damm field is hosted by an Ocean Core Complex and there is clear evidence for ultramafic influence in the fluid chemistry (McDermott et al., submitted). The Piccard site, at 5000m, comprises multiple active and inactive mounds indicative of sustained, neovolcanically-hosted venting (Kinsey and German,

submitted). Here, ~400°C fluids are unusually rich in dissolved H_2 while mixed fluids show evidence for *in situ* abiotic organic synthesis.
Broader Impacts: This project is the focus of female graduate student Jill McDermott's PhD research at WHOI/MIT. Outreach to-date includes expedition blogs; a SCAD undergraduate video-project; a 6-article science journalism series published in *Astrobiology*; and 3 oil-paintings displayed in the *Ocean Synergy* collaboration at Boston's Museum of Science (Feb-Jun 2013).

5.b) K.Bell (Ocean Exploration Trust) - This PI has received no prior NSF support.

5.c) A.Pallant (The Concord Consortium)

Award: A. Pallant, H-S, Lee, & P. Norris; DRL-1220756; 10/1/12 – 1/31/16; $2,328,000.
Title: High-Adventure Science: Earth's Systems and Sustainability (HAS:ESS).
Intellectual Merit: This project seeks to research the effectiveness of curriculum materials to reliably convey an understanding of Earth's systems and the increasing role of human interaction with those systems, while also introducing important science practices and cross-cutting concepts. It builds on the results of prior work but to expand the number of concepts, the project is developing additional modules for middle and high school Earth and Space Science classes. Our project is to develop these modules in collaboration with UCSC and the National Geographic Society, conduct the research, and disseminate the materials via far-reaching education networks.
Broader Impact: The project will create a rich legacy of materials, including online curriculum modules, teacher guides, and research.

5.d) S.Jasanoff (Harvard Kennedy School)

Award: S. Jasanoff & S. Kim, SES-0724133, 9/1/2007-8/31/2010, $350,000
Title: Sociotechnical Imaginaries and Science & Technology Policy: A Cross-National Comparison
Intellectual Merit: Through a 3-country comparative study (including the US, S.Korea, and Germany), this project developed the concept of "sociotechnical imaginaries" to advance our understanding of the national and transnational politics of science and technology (S&T). The project resulted in: (1) data collection on policies and public debates related to three projects (nuclear power, stem cell research, nanotechnology); (2) theoretical reflection on and elaboration of the sociotechnical imaginaries concept.
Broader Impacts: The project helped to train two postdoctoral fellows, as well as several STS fellows and Harvard undergraduates, and built links with two European centers around the imaginaries concept (Bergen, Norway & Vienna, Austria). Finally, the project gave rise to a new, web-based, research and teaching tool: the "research platform" on sociotechnical imaginaries designed & maintained by Harvard's STS Program.

5.e) K.Rajan (Monterey Bay Aquarium Research Institute)

Award: G.S.Sukhatme (USC), J.Dolan (CMU), K.Rajan (MBARI); IIS-1127975; 08/01/2011-07/31/2014; $725,000.
TItle: Collaborative Multi-robot Exploration of the Coastal Ocean
Intellectual Merit: This project couples human decision-making with probabilistic modeling and learning in a decision support system enabling environmental field model discovery and refinement. It has extended the state of the art in multi-robot adaptive sampling by investigating the relationship between environmental field structure and sampling performance, developing improved field boundary tracking techniques, and creating methods for multi-resolution, multivariable sampling. We have demonstrated these general principles in the specific domain of coastal ocean exploration, but expect them to be broadly applicable across robotics and computational intelligence.

Broader Impacts: Decision support with diverse data integrated in a form that is interpretable by a non-computer specialist will have broad impacts applicable to a range of other domains, including disaster response and military and homeland security.

6. Broader Impacts

This project will yield Broader Impacts at many levels. Within the INSPIRE team itself, it will provide one female researcher at the OET with their first experience as an NSF PI; it would also afford extensive post-doctoral experience to another female at the Harvard Kennedy School.

Within the Ocean Sciences, our project will provide valuable field opportunities to a cohort of talented early career scientists (two female) pioneering the field of *in situ* remote sensing to understand the sources and fates of important greenhouse gases released to the deep ocean. We will also provide novel and engaging access to oceanographic research for a cohort of 12 undergraduates, half from non-traditional Universities in terms of deep ocean research. More broadly, the lessons to be learned on how best to adapt telepresence to the future of ocean research will be profound. Multi-disciplinary research in the deep ocean remains compelling in pursuit of societally relevant issues (climate change, ocean acidification) but the arrival of two new Ocean Class research vessels will require this community (including the Lead PI for this proposal and the early career science team members), to find new ways to conduct research, using fewer berths at sea. Assuming that we do not want to downgrade the quality of the technical operations (e.g. ROV, AUV operations) from these smaller ships *and* that we want to increase, not decrease, opportunities to engage and recruit new researchers and students into the field then development of telepresence can be perceived as a requirement for the future of Oceanographic research and education. This collaboration, based at the Inner Space Center will allow us to compare practices already established for both the “Scientist on Shore” (*NOAA OE*) model and the “Scientists on Call” (OET) model and evaluate which from each approach fits best to future NSF needs. Finally, the open access data sharing and publication protocols that we will experience and work through in this project will also be invaluable in the run up to NSF’s Ocean Observatories Initiative.

The impacts of this project will also extend far beyond the Oceans, however. Telepresence enables scientific discovery from afar, compressing the physical distance and time of participatory exploration via new extensions of the human senses, with resultant disruptive methods in data gathering and analysis. The protocols we establish and the interactions we achieve will rely, heavily, on new methods to deal with large amounts of data and novel computational methods, often from the proximate fields of AI and Robotics. Examples of wider benefits might include developing new approaches to explore, identify, authenticate and tag data, which can be used for Machine Learning. Scientists in many fields whose working communities have not previously used remote telepresence are now interested in developing the use of such tools.

Perhaps the most exciting feature of the proposed research is the potential to use telepresence, increasingly, throughout the STEM fields, to excite, entrain and recruit next generation researchers. From one prior experience (July 2012) we have already seen the potential for students to be transformed from ocean novices to exploration leaders in a 2 week “Tele-Cruise”. Clearly there is huge, untapped potential in this approach. The nature of *any* telepresence-enabled research is that it provides access to such large volumes of data that students will need less emphasis on learning how to obtain data (e.g. through field observations or experiments) and more emphasis on learning how to think about those data and use tools to extract information from datasets. Few programs offer such total immersion but we anticipate this will provide a richer and more rewarding learning experience.

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