Developing Practical Data Skills in Undergraduate Students Using Ocean Observatories

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Abstract
Developing the workforce to meet the needs of the blue economy will require changing undergraduate marine science programs to provide a wider range of skills developed by “doing” rather than just “reading.” Students also need training on how to effectively work in a team, critically analyze data, and be able to clearly communicate key points. With that in mind, we developed a new undergraduate course (called Ocean Observing) focused on conducting research by analyzing data collected and delivered to shore in near real time from the growing global network of ocean observatories. The course structure is based on student teams that use data to develop a range of data products, many of which have been suggested by state and federal agencies as well as from maritime companies. Students can take the Ocean Observing course repeatedly throughout their undergraduate career. A complimentary second entry course (called Oceanography House) was developed to entice freshmen first-term students into research on their first semester on campus. The Ocean Observing course has increased the number of marine science majors and the overall diversity of the marine science program and resulted in a dramatic increase in the number of independent student theses conducted each year. Over the last 10 years, student data profiles from the course emphasize the importance of conducting research in a public way so students can partake in the “adventure” of research before the outcome is known. To increase the public visibility of these “adventures,” collaborations between departments across the campus have developed nationally broadcast documentaries and outreach materials. Going forward, we seek to build on this success by developing an accelerated Masters of Operational Oceanography and link these undergraduate students with external companies through externships and coordinated research projects.

Keywords: undergraduate education, ocean observatories

Introduction
Today’s undergraduate students face an increasingly competitive job market populated with a mobile global population of workers. For students to be competitive upon graduation, they need to have advanced technical/numerical and social skills (National Research Council [NRC], 2012). Guidance to educators interested in workforce development for the blue economy was gathered through a discussion panel, consisting of industrial-teaching-research experts, at the 2017 Oceanology International North America Conference. Specific guidance indicated that workers must understand both why they are collecting data (a collaborative skill) and how to accomplish the goal (a technical skill). These data are never perfect, and one must understand how sensors and platforms work to fully understand their limitations. It was noted that many of today’s students do not have the opportunity to go to sea, yet the need to grow the workforce is beyond our ability to provide traditional training at sea onboard a research vessel. Students therefore must gain this experience through new approaches (Kolb, 1984). Present training approaches need to be more experiential, where students are encouraged to ask questions and determine if the data make sense (NRC, 2012). Individuals should be trained to collect and review data, understand them, and work collaboratively to understand what they really mean as a launching point for where to go next. Ultimately, to be employable in the marine sector, the students need to have worked with real data and be ready to solve technical problems, analyze data in real time, and collaborate with a broad range of people in
day-to-day operations. Undergraduate educational training rarely provides practice with all of these skills. On the other end of the spectrum, a full 4- to 5-year PhD experience is more than what is needed for an operational or technical level oceanographer. A shorter but intensive program that goes beyond the general undergraduate education to focus on operational needs of collecting, processing, and making data available to end users is what is missing.

Beyond developing new educational programs, another major challenge is making sure we reach the entire potential workforce in order to entice the growing communities' full diversity and range of talented students. The National Academies Committee on Science, Engineering and Public Policy (CSEPP) has recommended that efforts be made to increase the percentage of 24-year-olds with degrees in the natural sciences or engineering from 6% to at least 10% (CSEPP, 2007). The challenge is compounded by statistics that show underrepresented minorities, who majored in STEM (science, technology, engineering and mathematics) at the same rate as others but completed their degrees at a lower rate (CSEPP, 2011) because of cultural and economic barriers (National Center for Science and Engineering Statistics [NCES], 2010). Studies suggest that U.S. institutions would need to quintuple the proportion of underrepresented minorities earning a first degree in these fields to achieve this 10% goal. This hurdle is even more daunting for geosciences, which has the lowest diversity of all the STEM fields at all levels of higher education (NCES, 2015). Traditional approaches of partnering between a small number of minority institutions alone will not be sufficient to meet the challenge.

Effective engagement of students from underrepresented groups hinges on effective mentorship and cultural competency on the part of faculty, staff, and mentors. Culturally responsive curriculum integrates African American, Native American, and Latino and Western knowledge systems around science topics with goals of enhancing the science skills and knowledge of students (Stephens, 2000). It assumes that students come to college with a set of beliefs, skills, and understandings from their experiences and it is critical to ensure everyone feels a fully integrated member of the community (Huntoon et al., 2015). Emphasis needs to be placed on recognizing and making connections to this understanding and assumes multiple ways of viewing, structuring, and transmitting knowledge of the world. A culturally responsive curriculum (1) includes topics of cultural significance that involve local experts, (2) links science instruction to locally identified topics and science standards, (3) includes opportunities for students to develop a deeper understanding of culturally significant knowledge linked to science, (4) uses teaching practices that are culturally compatible and focus on student understanding, and (5) develops culturally aware assessments.

A New Ocean Observing Course Grounded in Ocean Technology and Data Anchoring the Classroom in Ocean Observing Networks

To meet these challenges, a decade ago, we developed a research course (called Ocean Observing) for undergraduates. Our philosophy was to develop a class that complements traditional lecture course structures where undergraduates, after taking their core foundational courses, move into specialized personalized research experiences working in faculty laboratories. Our solution was to form a data immersion class that would help students fulfill their research requirements for their degree throughout their undergraduate career. The Ocean Observing course has no prerequisites, allowing any students to take it as many times as they wish starting their freshman year. This had the positive impact that, in some semesters, close to 30% of the students were nonscience majors, thus increasing ocean science literacy outside the subject matter experts. Several students have taken Ocean Observing seven consecutive semesters over the eight terms in a 4-year degree. This model also opens up research experiences for working students who must, all too often, pay their own way through school, thus limiting the time they have to participate in research outside class and during the summer.

The heart of our class is using the expanding number of ocean observing networks, allowing students to access data, often in real time, that allow for intensive data immersion efforts providing practical hands-on experiences. We believe that the Ocean Observing course is a hybrid cognitive apprenticeship model, where students move through three levels of participation, frequently described in simple terms as "watch one, do one, teach one." Typical classes of 50–70 students each semester are organized to keep students engaged. They are organized to work in a smaller focused research team of five to seven people (Springer et al., 1999) that is led by an undergraduate
mentor who has taken the class several times and has expertise to pass onto the new students. The team is responsible for conducting an original data project that is based on streaming or historical data from the ocean. Students access data from systems that can range from profiling floats, gliders, seafloor cables, numerical model simulations, radio-tagged animals, and commercial fishery data. As efforts are based on ongoing real-time experiments in the ocean, projects change each semester and thus the students do not repeat the same analysis term after term. This is one of the most important parts of the Ocean Observing course as the students each term must design a data analysis strategy. This requires that the team develop a clear list of priorities and distributed work flows in order to accomplish the work in a single semester. The team leader’s experience is key to that process. Students must have demonstrated expertise in developing and conducting end-to-end data synthesis before becoming a team leader. To assist the leader, we conduct separate leadership training with all the prospective team leaders at the beginning of the semester. The focus of that training is on how to organize and motivate a team. Students as a team choose a topic of interest. There is flexibility for the students to choose a topic that allows them to focus on a topic that is relevant to them.

To ensure the students are producing data products that have value outside basic research, we solicit projects from potential end users outside the university who use marine data. For example, the Head of the Weather Service attended our class and challenged the students to document the predictive skill of the operational European and North American ocean models using global gliders and profiling floats. Commercial companies have had student teams test/validate their new sensors that they hoped to bring to market. The data synthesis for each group is presented at the end of each semester in a science symposium that features a high-level invited speaker who is asked to provide his or her personal story of his or her career and offer advice to the students in their future careers. The symposium is open to the wider marine science communities on campus, and students must provide clear oral and visual synopsis of their research. To support this, lectures are focused on the most effective means for presenting information. Student projects have ranged from planning navigation routes for gliders worldwide; assessing the predictive skill of ocean models, hurricane, and winter storm ocean-atmospheric dynamics; assessing the water quality status of the Mid-Atlantic Bight; improving glider energy efficiency and adjustable ballast control; and the foraging ecology of penguins outfitted with radio tags. The high-level speakers have included the director of the National Weather Service, the program manager from the Integrated Ocean Observing Service, and a former Oceanographer of the Navy.

Students taking the class more than once are exposed to a wide range of skills beyond analyzing scientific data that will be critical to their future careers. Students improve communication skills by giving two public presentations each semester, working/collaborating in a team, developing prioritized data synthesis strategies, and organizing the work flow so the team can meet the semester deadline. The diversity of science and nonscience students requires the team to leverage the diverse skills within the group. Finally, students broaden efforts beyond data exploration to developing information that has practical value based on guidance from experts outside the professors teaching the class.

Introducing First-Year Students to Research Opportunities

To entice students early in their undergraduate degrees, we developed a learning community for oceanography on campus. A learning community is a self-selected group of students who share similar academic interests and explore them together in common courses and out-of-classroom activities. The oceanography learning community was established for incoming freshmen during their first term on campus. The Oceanography House course begins with a series of lectures by senior level faculty introducing them to research opportunities on campus. Students then conduct a field excursion to collect data in aquatic systems and a basic synthesis of the data while learning a range of basic software tools (Google Earth, Excel, and MATLAB). The primary goal is to introduce students to the research opportunities available to them and encourage them to participate early and often in their undergraduate career. Research is not reserved for advanced career students. The Oceanography House course has been fully subscribed whenever the course has been offered. After the first term, students can join the Ocean Observing course.

Lessons Learned After a Decade

This series of courses have now been in place for a decade allowing for examination of the classroom demographics. The data provide some clear lessons, as discussed below.
Enrollment Increases Dramatically for Declared Marine Science Majors During Public Experiments and Continued Visibility is Critical to Maintain Growth

The faculty were challenged by the National Oceanic and Atmospheric Administration (NOAA) in 2007 to have undergraduates pilot an autonomous underwater glider to cross an ocean basin. A Rutgers donor provided funds to allow the mission to proceed, and our team with the undergraduates focused on successfully navigating a glider across the Atlantic Ocean. This was the early genesis of the Ocean Observing course. Student teams successfully navigated a glider from New Jersey to Spain, which was the first ocean basin crossing by an autonomous underwater robot. The transatlantic glider was a highly visible event, and the excitement translated directly into a significant increase of marine science majors. Enrollment jumped 41% during the culmination of the event, and the numbers remained high for a 4-year graduation cycle (Figure 1A). We see that our gender distribution is close to 50% female and 50% male (Figure 1A). This was a highly public mission that was recognized by the White House and the Spanish government. Since the highly public mission was completed, student numbers have declined but still remain 26% higher than prior to the transatlantic glider expedition. These results suggest that the visibility and being part of an adventure during their undergraduate career are a critical element that speaks to the core motivation of being a scientist or an engineer, which is rooted in the excitement of exploration, risk, and communal teamwork/debate. While we have completed several ocean crossings since the transatlantic mission, our efforts to engage the public were not as focused as the first crossing (we were overcommitted). Realizing this, we are now planning to improve our visibility around ongoing global glider surveys in order to increase our undergraduate majors by ~30%. The plan is to develop the tools to allow the undergraduate students to be our ambassadors. Based on our experience, we believe that these messages must be embedded into the university mission.

**FIGURE 1**

(A) Number of Rutgers marine science majors over the last 12 years. Symbols in blue represent the number of female (open circle) and male (closed circle) students. (B) Number of marine science majors who are non-Caucasian. (C) Number of formal research theses presented over time.
and messaging. Communicating efforts publicly as experiments/expeditions are happening adds to the element of uncertainty of success and allows the students to feel the ownership in the adventure. We believe that developing these approaches could be extremely effective, and universities should embed this excitement into their science programs.

Visibility Increased the Diversity of the Rutgers Marine Science Program

Prior to the transatlantic crossing, the percentage of non-Caucasian students studying marine sciences was consistently ~10% (Figure 1B). During the experiment, non-Caucasian marine science majors doubled. Interestingly, while the total number of marine science showed declines when the public experiment was completed, the diversity numbers have remained stable, with ~20% of the marine science majors being non-Caucasian. The philosophy and mentoring practices in the course align with recent findings of the social cognitive career theory (Curtin et al., 2016)—that it is important to focus on different kinds of mentoring including instrumental (skills and knowledge), psychosocial (personal support, encouragement, and advice), and sponsorship (active advocacy of the individual’s opportunities within the institution and open access to the mentor’s own network of professional contacts). Our mentorship model includes attention to the academic career self-efficacy, interests, and goals of the student. This is greatly facilitated through the near-peer cognitive mentor model of the course. The goal of the mentoring program is to provide the skills, knowledge, and experience to prepare students to excel in his or her career path. The student development is enhanced through a program of structured mentoring activities.

Increased Undergraduate Independent Research Projects

Students must often earn research credits to graduate with science degrees from many universities. Often, this can be accomplished by taking credits earned by working in faculty laboratories. There are often formal programs that allow students to simultaneously conduct independent research projects that are a significant increase in effort beyond bare minimum graduation requirements. Associated with the transatlantic glider crossing, there was a more than 100% increase in the number of students conducting formal independent research projects (Figure 1C). The number of students conducting independent research projects has not decreased since the completion of the transatlantic glider mission. These projects, beyond fulfilling undergraduate degree requirements, have resulted in students being lead authors on manuscripts and presentations at professional societies such as the American Geophysical Union, the American Society of Limnology and Oceanography, and the Marine Technology Society (Figure 1C, inset).

Increasing the Visibility of the Research

Given the importance of being “visible” to increase the numbers and diversity of the students, we as a community must conduct as much of our work in public as possible. We must share our victories as well as our defeats. This is difficult and a skill set too often residing outside the science and engineering departments. To this end, we formed partnerships with other departments (English, Art, and Music) to help translate the science effectively to a wider range of society (Figure 2). For the transatlantic glider, the Rutgers Writers House, associated

**FIGURE 2**
The fliers for the two undergraduate-developed movies.
with the English department, embedded students in the laboratory and filmed the entire journey with the undergraduate students throughout the effort. Together, they produced and edited a documentary, Atlantic Crossing: A Robot’s Daring Journey (https://marine.rutgers.edu/main/main/marine-movies-from-dmcs), that went on to win accolades at 16 film festivals and was broadcast nationally on the Public Broadcasting Service. This was followed with another film where undergraduate art and music students edited several thousand hours of footage and music students wrote an original score to produce a second film, Antarctic Edge: 70 Degrees South, that went on to win nine awards at international film festivals.¹ These efforts provided an effective outreach tool and a positive mode to increase recruitment into the sciences and engineering. The added advantage was science faculty and undergraduates, in order to entice the Art-English-Music students lectured in those departments, which increased overall science literacy and provided context for the student-driven creative efforts. It also entrained nonscience students to enroll in the Ocean Observing class.

Looking Forward and New Education Opportunities

The last decade has demonstrated utility of these immersion research programs. Looking forward, we are beginning to think about how to continue to increase student opportunities for gaining practical hands-on experience in order to give them a competitive edge for employment upon graduation. We are currently focused on the two efforts discussed below.

An Integrated Ocean Observing Systems Master’s Degree

The team has designed a new Operational Masters in Integrated Ocean Observing slated to begin in the summer of 2019. The program is designed as a compact 15-month program, composed of two semesters of coursework sandwiched between two summers of research that can fulfill all the requirements for a Master’s degree. For many students, this effectively provides a mechanism for a 4+1 Bachelor/Master degree program. The first summer includes a software boot camp, where students are spun up on typical data analysis software such as R, MATLAB, and Python. They also receive training in standard oceanographic data formats such as netCDF and oceanographic toolkits for data/model analysis and delivery systems such as ERDAP. Over the course of the school year, there is a two-semester course sequence introducing students to a wide variety of Eulerian and Lagrangian platforms and sensors that comprise modern ocean observing networks. Each type of platform or sensor has a series of classes that introduce the sensor and quality assurance protocols, how to access the data, and application of specific quality control measures. Data are processed, and each student orally presents the results of his or her homework to the rest of the class—a practice designed to enhance oral communication skills. The course is interspersed with coaching classes on best practices in data visualization techniques and how to communicate with data. This is complemented with a yearlong field laboratory where students have hands-on opportunities to prepare, quality assure, deploy, operate, recover, quality control, and curate data that they acquire within existing ocean observatories. There is a two-semester sequence focused on data analysis and numerical modeling techniques. Model validation with data and the impacts of data assimilation are included. The capstone is an operational Master’s thesis conducted during the spring and final summer based on the MTS/IEEE OCEANS conference. Students work with a faculty advisor to submit an abstract to the OCEANS conference as their thesis proposal. Their research is completed over the spring and summer and culminates with submission of an MTS/IEEE OCEANS conference proceedings paper. As the courses are matured, international accreditation by the U.K.-based professional body Institute of Marine Engineering, Science and Technology program will be sought to ensure that the courses meet the educational needs of the maritime sector.

Undergraduate Internships

Support from Teledyne Webb Research provided support for summer undergraduate drawn from oceanography undergraduate course. These students helped pilot underwater gliders conducting global scale missions through the educational Challenger mission (https://challenger.marine.rutgers.edu/). The focus of these students was to assess the accuracy of the global ocean operational models against real data collected by Slocum gliders. The students were able to compare the predictions of an ensemble of European and American model outputs against the real-time data collected by open ocean gliders deployed by the faculty and the

¹Available at iTunes.
Ocean Observing course (see above). The undergraduate students authored and presented their results at the annual MTS conference. This success resulted in the Rutgers Alumni class of 1950 forming a summer student endowment to ensure students could have the opportunities to continue in this education/research effort. Our goal in the coming years is to expand this summer effort by building a series of externships where students can gain valuable experience working with marine companies. This would provide students a range of hands-on skills and also benefit the industry partners, providing them a direct recruitment tool of future workers with no obligation of permanent employment.

Acknowledgments

We thank Rutgers University that has always been supportive for encouraging us to explore and develop new education programs. We acknowledge Rutgers donors who have purchased gliders and created student endowments to support our undergraduate teaching efforts. The education/outreach work is being supported by the National Science Foundation (PLR-1440435), the Vetelsen Foundation, NSF Palmer LTER program (Grant 0823101), NOAA IOOS award to MARACOOS (NA11NOS0120038), and the Teledyne-Webb Student Fellowship. We also appreciate helpful suggestions provided by anonymous reviewers.

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