

DISTRIBUTED OCEAN ROBOTS ARE A KEY TO ENTRAINING THE NEXT GENERATION INTO OCEAN LITERACY AND LIFELONG LEARNING

Oscar Schofield⁽¹⁾, Josh Kohut⁽¹⁾, Janice McDonnell⁽¹⁾, Scott Glenn⁽¹⁾

⁽¹⁾*Rutgers University's Center for Ocean Observing Leadership (RU COOL), Department of Marine and Coastal Sciences, School of Environmental and Biological Sciences, Rutgers University, New Brunswick, NJ, 08901*

ABSTRACT. The increasing global network of ocean observing networks is increasingly providing free and open access to ocean data. The networks provide a diversity of data in a wide range of locations spanning from polar to tropical seas. We have found that these real-time robotic networks are a great magnet with which to entrain both science and non-science undergraduate students. To focus student efforts, we developed a research course where students had to learn how to read data from the glider, interpret ocean models and satellites imagery and make informed decisions for the glider flight path. Popularity of the course was high and our solution to accommodate the growing number of enrollees was to form a research class that would help students fulfil their research requirements for their degrees. The course is based a cognitive apprenticeship model, student's progress 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 into research teams of 5-7 people led by a more senior student mentor. The publicity associated with the student resulted in increased enrolment, improved diversity and increased the number formal theses being submitted. The efforts were also an effective bridge to other Departments across the University (English, Art, and Music). The materials developed by the courses in turned provided a foundation of materials to enable outreach efforts to formal and informal lifelong learning communities.

INTRODUCTION. Today's undergraduate students face an increasingly competitive job market reflecting the needs for advanced skills and a growing and mobile global population of potential workers. While a small proportion of undergraduates continue their education for higher degrees (MS, PhD), the majority undergraduates enter the job market often with limited hands-on experience. The lack of practical experience often is the result of the structure of many undergraduate programs combined with limited opportunities for students to work in the field/labs. Most degree programs in the initial years of a student's experience has a necessary focus on core foundational lecture classes augmented with laboratory classes designed to illustrate key principles. While critical to providing the knowledge foundation for the students, they are generally not designed to allow for much free-form exploration and experimentation which is a critical skill to being a successful professional scientist or engineer. It is not until halfway (junior or senior years) through their undergraduate careers that students begin to get "real" research experiences with faculty. This limited window of time combined with there being more students than can be accommodated within existing faculty labs often leaves a significant proportion of students graduating with limited experience in building tools, synthesizing data, and iterating on experiments. Technological innovations in autonomous systems coupled to global communications offer new opportunities to alter undergraduate access to conducting research. This has been a focus of our group over the last decade and here we review lessons learned using ocean observing systems in our classes.

OUR HISTORY OF USING ROBOTIC TECHNOLOGY TO MAKING UNDERGRADUATE LEARNING A "LIVE" EXPERIENCE. The increasing global network of ocean observing networks is increasingly providing free and open access to ocean data. The networks provide a diversity of data in a wide range of locations spanning from polar to tropical seas. Our interest was to

link an undergraduate research experience to these live data streams. This was in part prompted by a challenge issued to our group by the Assistant Administrator for the National Oceanic and Atmospheric Administration to engage undergraduates in high risk research efforts conducted in a public way where failure was possibility.

To that end, the team decided to conduct a student driven effort to navigate an autonomous underwater glider across an ocean basin. The initial cadre of students was small (5), and working with faculty they prepared the glider and helped pilot a glider that was launched from New Jersey in April 2008. Students had to learn how to read data from the glider, interpret ocean models and satellites imagery to make informed decisions for the glider flight path. The glider made it to the Azores where it was unfortunately terminally damaged by a shark attack, providing invaluable reality of science that many efforts/ideas fail; however the lessons learned enabled the next science/engineering effort. Undergraduates were devastated but regrouped and then focused on a second attempt. The shark attack and the engineering data downloaded before the glider entered Davey Jones's locker, lead to a redesign of the CTD which was the point of failure. On April 2009 a second glider was launched, outfitted with a reinforced bracket for the CTD, and was coordinated with a growing group of students as research class had been maintained every term since the first glider deployment. Publicity across campus, regional community groups and in the news media increased the visibility of the effort and student involvement grew dramatically requiring the faculty to formalize a structure to efficiently coordinate student involvement in the efforts that have since supported NSF and NOAA programs.

Our solution was to form a research class that would help students fulfil their research requirements for their degree. The course had no pre-requisites allowing any student across the University to take the course even in their freshmen year for as many times as they wished. This had the positive impact that during some terms close to 30% of the students were non-science majors all gaining hands-on training and increasing their science literacy. The course is based a cognitive apprenticeship model, student's progress 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 into research teams of 5-7 people led by a more senior student mentor. The team is responsible for conducting a research project that can be based on streaming and historical data. The semester-long data synthesis for each group is presented at the end of each semester in a science symposium that features a high level invited speaker to inspire the students in their own future careers. While inexperienced students are taking the course often in the mode of "watching" the more experienced students become the "teacher" providing them valuable mentorship experience which includes training in how to be a good mentor. Student projects have included planning navigation routes for gliders world-wide, assessing the predictive skill of ocean models, hurricane and winter storm ocean-atmospheric dynamics, improving glider energy efficiency and adjustable ballast control, to the foraging ecology of the penguins outfitted with radio-tags. The high level speakers have included the Head of the National Weather Service, the program manager from the Integrated Ocean Observing Service, and former Oceanographer of the Navy.

To entrain 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 community is coordinated by senior level faculty introducing them to research opportunities on campus, conducting 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 course has been fully subscribed every term that it has been offered. After the first term students then join the existing Ocean Observing course.

This program has now been in place for a decade allowing for examination of the course demographics. Results provide some clear lessons:

Enrollment increased dramatically for declared marine science majors during public glider experiments however continued visibility is critical to maintain growth. The trans-Atlantic glider was highly visible event and this excitement translated directly into a significant

increase of marine science majors. Enrolment jumped 41% during the culmination of the event, and the numbers remained high for a 4-year graduation cycle (Figure 1A). Since then numbers have declined but still remain 26% higher than prior to the glider expedition. These results suggest to us that visibility and being part of an adventure during a degree is a critical element that that speaks to the core motivation of being a scientist or engineer rooted in the excitement of exploration, risk, and communal teamwork/debate. We suggest these messages must be embedded into the University mission and messaging. Communicating efforts publicly adds to the element of uncertainty of success and can allow the students to feel the ownership in the adventure. We believe developing these tools are extremely effective that universities should embed into their programs.

The importance to promote science in a range of venues to communicate the excitement is difficult and a skill set to 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 flight, the Rutgers Writers House associated within the English Department, embedded students in the lab and filmed the entire journey with the scientists throughout the effort. Students with English faculty

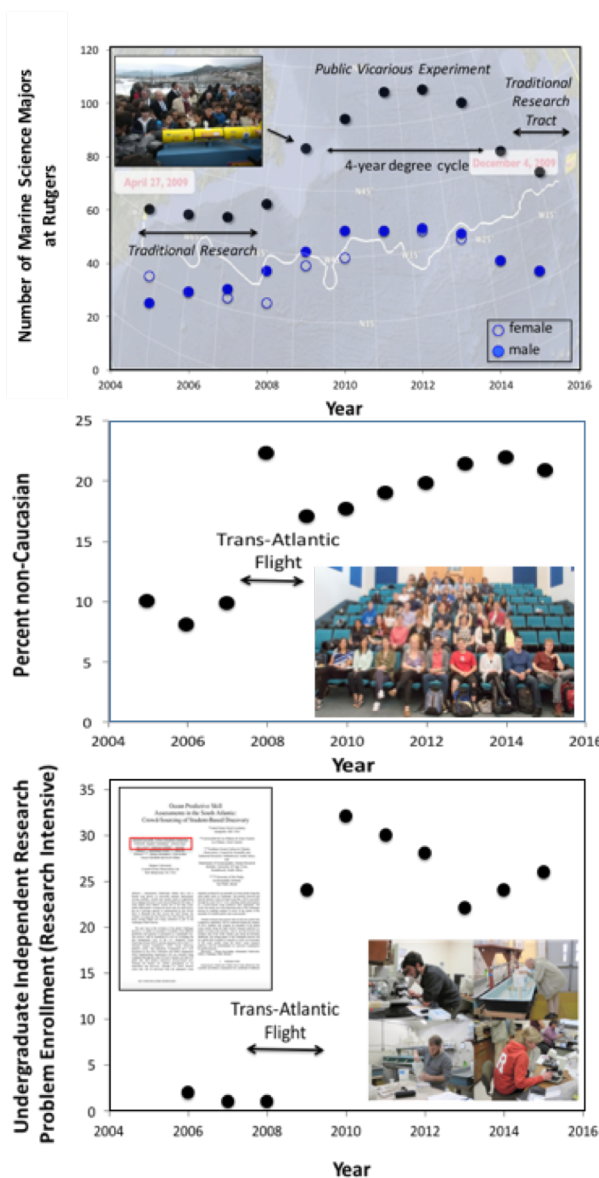


Figure 1. Statistics of the Rutgers Department student enrolments over a decade. 1A) Total number of female and male undergraduates enrolled as marine science majors. The impact of global gliders mission initiated in 2008 is clearly visible. 1B) The relative proportion of the majors that were non-Caucasian. 1C) The number of undergraduates who enrolled formally to conduct formal research thesis.

produced and edited a documentary, *Atlantic Crossing: A Robot's Daring Journey*, that went on to win accolades at dozens of 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 >10 awards at international film festivals. These efforts provided an effective outreach tool and provided a positive message with which to increase recruitment into the sciences and engineering. The added advantage was science faculty, in order to entrain the Art-English-Music students, lectured in those Departments which increased overall science literacy and provided context for the student-driven creative efforts. These non-science students went on to often being very engaged in promoting the science message. A common theme we discovered it was not the science that was the “hook”, it was the robots. Robots were the gateway drug to entrain students to then take interest in learning about the science.



Figure 2. Two feature length movies developed, edited and scored by Rutgers undergraduates drawn from English, Music, and Art Departments. These nationally broadcast films became a unique means to entrain non-science students in telling science stories.

Highly visible public efforts increased diversity in the marine science program, and this diversity did not decrease when publicity subsided. The National Academies Committee on Science, Engineering & Public Policy has recommended efforts be made to increase the percentage of 24-year-olds with degrees in the natural sciences or engineering from 6 percent to at least 10 percent (CSEPP, 2007). The challenge is compounded by statistics that show underrepresented minorities, who majored in STEM at the same rate as others, completed their degrees at a lower rate (CSEPP, 2011), due to cultural and economic barriers to completion (Aud et al. 2010). Studies suggest U.S. institutions would need to triple to quintuple the proportion of underrepresented minorities earning a first degree in these fields to achieve this 10 percent goal. Prior to the Transatlantic crossing the percentage on non-Caucasian students studying marine sciences was consistently ~10% (Figure 1B). During the experiment, the non-Caucasian marine science majors doubled. Interestingly while the total number of marine science showed small declines when the public experiment was completed,

the diversity numbers have remained stable, with ~20% of the marine science majors being non-Caucasian.

Increased undergraduate independent research projects. Students must often earn research credits to graduate in many Universities. Often this can be accomplished through taking credits earned through the working in faculty laboratories. There are often formal programs that allow students to conduct independent research projects which requires efforts beyond completing the unit requirements. Associated with the glider crossing, there was over a 100% increase in the numbers 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 glider mission. These projects beyond fulfilling undergraduate degree requirements also resulted in a student projects, as lead authors, presented at professional societies that include American Geophysical Union, the American Society of Limnology and Oceanography, and the Marine Technology Society (Figure 1C inset).

OUTREACH BEYOND OUR UNDERGRADUATE STUDENTS. Beyond our classrooms, our team has found that robots are extremely effective tools for education/outreach (EO), and therefore have been working with diverse collaborators to develop tools/curricula associated that use glider technology. Since 1996, we have focused on creating meaningful science experiences for middle and high school classrooms through data rich activities that highlight how science research practices are conducted. These kinds of contributions are critical to current education reform efforts needed for compliance with the Next Generation Science Standards (NGSS). The goal of the NGSS is to move science instruction away from disconnected facts and toward inter-related ideas, which learners can use to explain scientific concepts and solve problems (Krajcik 2014). Observing Systems, especially glider technology, represents an exciting new paradigm for these internet-based ocean explorations.

Our efforts early on were enabled through the National Science Foundation's Centers for Ocean Science Education Excellence Networked Ocean World (COSEE NOW) program that focused on building an online network of scientists and educators focused on using ocean data from emerging Ocean Observing Systems (OOS) technologies for public education. The focus was on engaging learners in real time data across a broad range of audiences including community colleges, the K-12 formal education community, and informal learning institutions. COSEE NOW focused on surveying, summarizing, and distributing knowledge from educators and scientists on their use of ocean data with the overarching goal to build the ocean science community's ability to use real-time data in education and public outreach.

Podcasts: Ocean Gazing. COSEE NOW and National Public Radio contributor Ari D. Shapiro, worked together to develop a podcast series focused on Ocean Observing technology called, Ocean Gazing. The audio series consisted of 52 episodes interviewing prominent scientists and educators involved in Ocean Observing science and technology development. Five of the episodes focused specifically on glider technology. Companion lesson plans were developed to help educators bring this cutting edge science to their classrooms and inspire a generation of scientists and technologists. The website despite being a decade old (coseenow.net/podcast/) continues to receive visits from educators working in formal and informal learning contexts and who are interested in integrating research and data in their teaching.

Ocean Science Extended Laboratory Education Programs at Liberty Science Center, NJ. Our team has many productive relationships with science museums around the country. Most notably, the Liberty Science Center, in Jersey City, NJ, partnered with our team to create and teach two-day programs focused on specific theme or topic for up to 25 students at

the Center. These programs continued to be offered with one of the more popular classes being the “seasonality in the ocean” which is anchored by glider data and technology.

Floor Activities with Ocean Robots. In addition, a simple glider activity called *Exploring Ocean with Robots* has been used as a floor activity at Liberty Science Center. This program uses hands-on activities to explain how buoyancy is used to propel the Slocum gliders, and introduces guests to the types of research data gliders collect. Center volunteers present the program three to four days a week to school groups and family groups of mixed age children and adults. At the end of the program the Center distributes sheets with a picture of a glider that children can color, and with links to the Rutgers University glider blogs and COOL room. Finally, as an alternative approach for connecting guests with glider research once they leave the museum, Liberty Science Center has created an audio clip guests can access via their cell phone. The clip utilizes audio collected as part of the Ocean Gazing podcast series of scientists discussing their research with Slocum gliders. It has been available to guests since August 2011 via the NSF-supported SNSE (Science Now Science Everywhere) capability in the museum.

Polar Interdisciplinary Coordinated Education (Polar-ICE) More recently, our team have developed additional educational initiatives through the NSF funded Polar Interdisciplinary Coordinated Education (Polar-ICE) program. This project aims to build the capacity of polar scientists in communicating and engaging with diverse audiences while creating scalable, in-person and virtual opportunities for educators and students to engage with polar scientists and their research through data visualizations, data activities, educator workshops, webinars, and student research symposia. Polar ICE is working to help educators gain access to polar data, data activities, lesson plans, and media, explaining polar science and technology. Polar ICE supports educators in developing skills in how to use real scientific data in their classrooms as well as support them in utilizing online data software tools to help students learn how to orient to data as well as interpret and synthesize data observations.

Science Investigator (Sci-I) Program The Sci-I Project seeks to increase teachers and students in grades 6-9 understanding of the authentic process of science through supporting them through developing, conducting, and presenting on a polar-related open-ended science investigation. By mirroring the process of science through such investigations and by developing personal relationships with scientists throughout the project, we hope to increase students’ identification with and engagement in science. The Sci-I program starts with a four-day professional development workshop for middle school teachers. The intention of the workshop is to unpack the nuances and realities of the process of science while enabling the teachers to experience first-hand participating in an open-ended polar science investigation enabled through real-time data. Real-time glider is often the most popular. Twenty-one educators from New Jersey and California participated from 10 different schools, with approximately 1500 students in 2015.

CONCLUSIONS. Real-time global communications combined with the robotic systems are offering a range new teaching opportunities. Our experience is these systems are extremely effective in capturing student imagination, and for developing the learning structures that allow them to feel involved in ongoing missions. This is a particularly effective strategy to keeping them engaged which leads to the next stage where the students become interested in the underlying science.

References

- Aud, S., W. Hussar, M. Planty, T. Snyder, K. Bianco, M. Fox, L. Frohlich, J. Kemp, and L. Drake, 2010. The Condition of Education 2010 (NCES 2010-028). National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC.
- CSEPP Committee on Science, Engineering and Public Policy. 2007. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, D. C: The National Academies Press.
http://www.nap.edu/catalog.php?record_id=11463
- CSEPP Committee on Science, Engineering and Public Policy, 2011. Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads. Washington, D. C: The National Academies Press,
http://www.nap.edu/catalog.php?record_id=12984
- Krajcik, J., S. Codere, C. Dahsah, R. Bayer, and K. Mun, K. 2014. Planning instruction to meet the intent of the Next Generation Science Standards. Journal of Science Teacher Education 25(2): 157-175.