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Front Cover: Courtesy of Mark Friedman (top left); Destinations Magazine (top right); Kimberly Willimas (bottom left and middle right); SSROV Camp (bottom right)
CURRENT LOG  We’re excited to bring you another general issue of Current featuring articles by NMEA members from all over the country and overseas to provide new ways to discover the “world of water.” In this issue, you’ll find a variety of engaging articles and activities, including how a week-long STEM summer day camp is helping young students learn more about seafloor exploration, as well as how educators are using tools like digital arts, a marine film series, and the Coriolis force in the classroom to inspire students and teachers.

From July 16-20th in Long Beach, California, marine educators from near and far will gather for our 2018 annual conference, Charting a Course for Conservation, hosted by the Southwest Marine Educators Association (SWMEA). The conference brings together formal and informal educators, scientists, students, and government and industry members to network and inspire. The conference hosts general and concurrent sessions, workshops, field trips, and evening events. Visit NMEA18.org for more details and register today, or contact the SWMEA conference coordinators at info@nmea18.org with any questions. We hope to see you there!

NMEA publishes two digital issues of Current each year, so please continue to send in your original manuscripts on research, lessons, resources, or strategies focused on marine and aquatic science, education, art, literature, and maritime history. Look for contributor guidelines on our website under Current: The Journal of Marine Education. The deadline for submitting articles for consideration in the Summer 2018 general issue of Current is May 14, 2018.

Remember to stay connected to the NMEA by liking us on Facebook and following us on Twitter for the latest news and updates.

Cheers,

Lisa M. Tooker
Editor

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Take the Plunge: A STEM Camp Centered on Seafloor Science

BY C. GEOFFREY WHEAT, TREVOR Fournier, KAREN MONAHAN, AND CLAUDIA PAUL

ABSTRACT
While most of the Science, Technology, Engineering, and Mathematics (STEM) efforts center on classroom programs, many lack hands-on activities that allow students to experience phenomenon-based learning and produce a complex scientific project. To meet this need, we developed week-long STEM summer day camps for two age groups: rising third to fifth and sixth to ninth graders. Campers learn about seafloor exploration through multiple hands-on, technology-rooted, team-based activities. At the end of the week, campers design and present research missions for an actual seafloor feature, incorporating hypotheses, methods, and operations.

Motivation
In the past decade there has been a push for STEM learning activities in K-12 and collegiate education. This aim is to foster a more technical, well-versed and informed community, spark advances that spur the economy, develop improvements in security, and ignite innovations in health and environmental sciences among other national and global needs and interests (National Research Council 2012). Our aspiration was to contribute to this educational objective by developing a week-long, STEM summer day camp (Seafloor Science and Remotely Operated Vehicle (SSROV) Camp (www.ssrovcamp.org). The camp provides an out-of-school opportunity that engages students through problem-solving skills and teamwork via hands-on STEM projects. Camp activities are grounded in current seafloor research and exploration expeditions and have a reach beyond the camp. The field of seafloor exploration captures the imagination, develops intellectual and teamwork skills, is relevant to a range of potential career choices, and is conducive to making connections between desktop activities and the environment (Humphris 2009). These components are recognized criteria for a productive out-of-school educational program (National Research Council 2015).

A premise for the camp is that seagoing scientists depend on detailed plans, innovative sensors and samplers, and the knowledge and resources to use and repair instruments at sea. Decades of experience working in the field of oceanography have taught us that within the marine research field there is a demand for technology-savvy professionals who can communicate with scientists, and for scientists who understand the technology they use for their research. This experience is conveyed to the campers who learn about the deep ocean, research equipment used at sea, and the roles and responsibilities of numerous occupations that are required for a successful expedition. Camp activities expand the minds of the campers by putting them in exciting real-life roles. Campers experience increased confidence and improved problem-solving and communication skills, as they engage with others in both imaginary and fact-based exercises.

Our aim is to promote problem-solving skills and teamwork through a hands-on STEM learning opportunity that culminates in the development of a proposed seagoing research expedition. These student-proposed expeditions are grounded in the geology, biology, chemistry, and hydrogeology of particular seafloor settings. Challenging science and technology-based activities merge both disciplines and raise awareness of their interdependencies. Seafloor science provides the backbone for phenomenon-based learning, whereas hands-on activities emphasize project-based pedagogy. In addition to science- and technology-based activities, the camp introduces complex operational problems and unusual operational events. These operational challenges make campers think and work together to find creative solutions. This is, perhaps, one of the most future-relevant aspects of the camp. Like professional ocean research, SSROV Camp emphasizes purposeful engagement and vision, planning and operations, teamwork and execution, and discovery and problem solving.

One desired outcome for the camp is personal development. While most campers are regular users of consumer technology (smart phones, tablets, computers, gaming, some programming, etc.), in camp they develop deeper technical knowledge and more nuanced skills. They learn about building technology based on a foundation of scientific knowledge, rather than just using available technology as it is presented to them. The second aspect of personal development is the broader reach provided by the interns. High school or early collegiate students mentor the campers.
and help them with problem solving. This is often the interns’ first exposure to real-life STEM careers, which we encourage them to pursue. Combined, SSROV Camp provides an environment where campers can be with like-minded peers and mentors, supporting each other in academic and technologically creative pursuits.

Why Seafloor Exploration?
Most experiences with the ocean are either on or in the ocean, but rarely under the ocean. Even exposure under the ocean is typically limited to snorkel depths or those of commercial submarines that are not only depth limited, but also generally available only near tourist destinations. The deep sea is dark and remote, engaging the imagination, especially given the unique life forms that have been recovered from depth (e.g., angler fish and giant squid). While the water column in the deep sea contains many unknowns, and new species are discovered on almost every remotely operated vehicle (ROV) dive (Sherlock et al. 2017), the seafloor provides an avenue to engage campers in learning about geologic, biological, chemical, and physical processes—and the advanced technologies that are required to collect samples and data from such a remote and harsh environment.

While much of the seafloor is covered by sediment with limited macrofauna (Glover and Smith 2003), there are oases of organisms and minerals where changing conditions are observed during yearly visits by ROVs and submersibles (e.g., Van Dover 2000). Such oases, for example, are observed along seafloor spreading centers (Figure 1). Here magma from the mantle heats seawater that circulates through the permeable upper basaltic crust forming hydrothermal vents. Some vents are black smokers and support microbial communities via chemosynthesis, which is the basis of the food web for local animals such as tubeworms, crabs, and mussels (e.g., Fisher et al. 2007; Tivey 2007). Seawater also circulates through the oceanic crust in many other settings including 1.) the ridge flanks (covering most of the abyss) with a volume of fluid discharge from the oceanic crust that is commensurate with the discharge of the world’s rivers to the ocean (Fisher and Wheat 2010); 2.) subduction zones (Saffer 2015); and 3.) continental groundwater discharge (Sawyer et al. 2016) (Figure 1). Combined, these settings offer a range of geologic settings, mineral deposits, fluid compositions, and biota—any of which may spark a camper’s imagination and interest.

FIGURE 1. Cartoon of primary geologic processes that result in the discharge of fluid from the crust to the ocean. Fluid discharge at spreading centers is driven by magmatic heat, whereas fluid discharge on ridge flanks is driven by lithospheric cooling and differences in crustal topography and sedimentation. Fluid discharge from subduction zones is driven by compaction and dewatering of hydrated minerals. Groundwater discharge into the ocean requires a permeable aquifer and pressure head. Warmer colored arrows represent warmer fluids. Courtesy of SSROV Camp
Because these settings are typically found at a depth of 2500m or deeper, advanced technologies are necessary to collect samples and data. These technologies include pressure tolerant components, high voltage electronics, robotics, and sensors. These items require mechanical, electrical, and software engineering skills, and operational specialists to design and deploy sensors and samplers on the seafloor, navigate surface and underwater vehicles, and program autonomous underwater vehicles. Thus, with the introduction of one general scientific umbrella, a range of technologies and potential occupations are introduced to the campers.

Components of SSROV Camp

Camps are currently designed for two age groups, students entering third to fifth grades (three- or six-hour duration depending on the venue) and students entering sixth to ninth grades (eight-hour duration). Both camps have four primary foci: 1.) the scientific method, 2.) engineering practices, 3.) operational realities, and 4.) mentoring. The overarching scientific theme for both curricula levels is the development of an expedition to elucidate aspects of fluid discharge from the ocean crust. For example, at the end of the week, groups of two to three campers in the sixth to ninth grade level present a complete “proposal,” which is the foundation for peer-reviewed science. These presentations are based on 1.) a multi-beam bathymetric map of a particular seafloor feature with fluid discharge; 2.) two fact sheets related to the general structure of the crust and the specific fluid chemistry, geology, and biota that correspond to that specific setting; and 3.) hands-on activities, seafloor videos, demonstrations, homework, and in-class discussions. Proposed research plans from the upper level teams are complete with hypotheses, methods, and operations. Proposals from the lower level have been less structured, but hit upon the major themes.

Engineering practices are promoted with each hands-on activity and presented in the context of the overall scientific theme or a particular aspect of a mission that is based on answering a scientific question. Both camps have a general schedule and theme that changes daily (Table 1). Within each theme are several topics that are emphasized with two hands-on activities in the morning and two in the afternoon. Each activity is preceded by a short discussion that places the activity in the context of actual seagoing operations, including images and videos of seafloor activities. The campers then complete the activity, which includes age appropriate mathematics, programing, and scientific rigor, often with informational sheets that include additional directions and questions. At the end of the activity, one or two of the groups answer a series of questions in front of the camp. Group discussions address what they did, how they did it, what worked, what didn’t work, and how they would change what they did to meet the desired goal or a goal of their choosing.

There is some duplication in themes between the two age groups, but activities differ, consistent with grade-appropriate vocabulary and explanations. Embedded in these themes is a connection to seafloor geology, biology, chemistry, and hydrogeology. Activities are based on a series of hands-on electrical, mechanical, and software engineering

<table>
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<tr>
<th>Day</th>
<th>Theme</th>
<th>Topic</th>
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<td>Monday</td>
<td>ROVs</td>
<td>Circuits, Motors, Buoyancy, ROVs, Manipulators</td>
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<tr>
<td>Tuesday</td>
<td>Autonomous Underwater Vehicles and Geology</td>
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<td>Sensors, Operations, and Fluid Discharge</td>
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<td>Thursday</td>
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<td>Operations and Proposals</td>
<td>Data Interpretation, Operations, Exploration Board Game, Geo-pardy, Proposal Presentations</td>
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</tbody>
</table>

TABLE 1. Overview of themes and topics for the sixth to ninth grade level camp. Actual activities make the most of the particular venue. For example, camps may spend most of one day on a pier (lake or ocean) or at a community swimming pool, affecting the order and duration of specific activities. The third to fifth grade level camp includes about half of these topics. Additional topics for the third to fifth camp include bathymetry, navigation, evolution, and seafloor scientific drilling.
Activities include: mechanics of using a manipulator to collect samples or pick up instruments from the seafloor, developing integrated systems to complete designated missions, and fabricating and calibrating sensors. For example, campers are given “unknown” samples for which they determine the concentration based on the calibration curve that they generate from their sensor circuit and a series of samples with known concentrations. Another example of an activity is one that focuses on operations and science conducted by seafloor rovers. Campers use computers to program small “underwater” rovers to complete designated patterns, thus learning how to program. Next, campers program rovers on a prescribed path related to their geologic setting, moving “seafloor instruments” from one site to another for “recovery” (Figure 2).

Each activity incorporates operational realities. Operational activities provide campers with an understanding of how to get sensors and samplers to the seafloor, navigate on the seafloor, and deploy and recover samplers and sensors through the design and operations of ROVs, autonomous rovers, and elevators. The latter are a means to deploy large or heavy instrument packages on the seafloor or recover samplers and sensors without recovering the underwater vehicle. Operational realities include a myriad of problems that arise, from a rover that is slightly misaligned to an ROV that loses a thruster. Operations also include logistics such as choosing the closest port to the site, the number of days to reach the site, the number of days on site, costs, etc.

Mentoring also is instrumental in the camp experience. The camp staff works with numerous counselors who are high school and early collegiate students. High school students are currently recruited from the Monterey Academy of Oceanographic Science and the Robotics Club at Presentation High School (the latter is a school for young women). While the counselor’s primary role is to ensure the safety of the campers, they also mentor the campers (Figure 3). While not revealing how to reach the most optimal solution(s), counselors provide advice to stimulate thought and guide campers as needed. The counselors also represent the gender and ethnic diversity of the community, providing role models for the campers.
Assessment
Multiple techniques for program assessment are employed to revise our teaching/learning approach, and for campers to reflect on and integrate current activities with previous ones. Of these techniques, the only enumerated approach is the pre- and post-camp questionnaires. These questions were designed to assess knowledge and provide a measure of successful and non-successful activities. The post-camp questions for the sixth to ninth grade level camp are:

1. Name three types of vehicles that are used to study the seafloor.
2. List the main components of an ROV.
3. Describe the adaptations your team made to its ROV and why you made these changes.
4. What is a breadboard and how is it used?
5. How would you calibrate a temperature sensor?
6. How do particles affect light transmission through the water, and what is the consequence of turbidity on data transmission?
7. Draw a seafloor elevator and label its parts.
8. Name and describe your team’s seafloor geologic feature. How do fluids discharge through the oceanic crust in this setting?
9. How would you quantify the number and density of organisms (fish, crabs, snails, etc.) on the seafloor?
10. What are three key operational activities that must be considered before embarking on an expedition to study or explore the seafloor?
11. What camp activity did you enjoy the most? Why?
12. What camp activity did you enjoy the least? Why?

About 50% of campers (39 of 78 total campers) in 2016 could correctly answer three of ten questions on the first morning of the camp. At the end of the week-long camp, more than 85% of campers could correctly answer eight of ten questions and more than 66% of the campers could answer all the questions. In 2016, the most enjoyable activity was split between the ROV and rover activities. The least favorite activity in 2016 centered on the use of quadrats to count organisms on the seafloor. This activity was revised before it was implemented in 2017.

Four other aspects of assessment are not formally enumerated. First, formative assessment and reflection are integrated within each activity. Upon completion of an activity, one or two of the student teams answers a series of questions to reinforce their understanding. Questions focus on the mechanics of the activity, and two questions that are more broadly based such as “How did it work/not work?” and “How is this technology used in daily life?” The latter is designed to increase awareness of their surroundings. Second, homework, which is assigned on the first three nights of the camp, is discussed the following morning. Homework also is designed as a medium to instigate discussion among the campers and their families at home, for campers to recount what they did, and to introduce a new topic that will be the focus of the following day. Third, campers play GEO-pardy, based on the concept of Jeopardy, which tests their knowledge of the seafloor, sensors, and operations that were presented in the camp. Lastly, teams make three presentations to the camp. One is based on the geologic and hydrologic setting of their particular seafloor environment. The second focuses on the biology and chemistry associated with fluid discharge at their site. The last presentation—at the end of the week—is one in which teams propose a mission to explore and investigate their particular seafloor environment (see Figure 4 on page 7), complete with hypothesis, methods, and operations. For each of these four assessment styles, camp staff (and camp counselors) asked additional questions to promote inclusion of all team members and to relate concepts to the broader oceanic environment.

Future Directions and Challenges
We are about to embark into our fifth year of offering SSROV Camps. Each year, the camp enrollment grows and challenges change. Camps are currently offered for two age groups and have expanded from six camps in 2016 (78 campers and 10 interns) to eight camps in 2017 (140 campers and 13 interns). This growth in the number of camps resulted from the development of a third to fifth grade camp, which was introduced in 2017. In response to parent and camper requests, we plan to expand the program to a more advanced skill level for students entering eighth to tenth grades. However, challenges in developing a more advanced program include: the cost in salaries to develop activities, and the purchase and modification of materials for the camp. For example, materials for sixth to ninth grade level camp cost ~$25,000 to purchase materials and prepare them for a 24-person camp.

Our near-term goal is to continue to expand to new locations. This presents challenges in finding suitable venues and keeping the camp fiscally solvent. We recognize the need to pay instructors, interns, and counselors competitively, especially given the limited number of camps that are offered each summer in certain geographic regions. We also recognize that areas that are largely populated by lower income families will require financial assistance, leading to the need for monetary contributions to provide camps in such areas. Last year about 15% of the campers were provided a scholarship to attend the camp.
Ultimately our long-term vision is to create a sustainable, nationwide program that spurs excitement for learning about the deep-sea environment and helps young people, especially those who might not otherwise have these experiences, to see themselves in the role of the explorer, scientist, engineer, technician, or operational specialist.

A major strength of the SSROV Camp is that it was developed and is currently taught by seagoing professionals and based on actual science drivers and mission operations. However, bringing the camp to additional locations poses new challenges, such as hiring suitable middle and high school teachers to lead the camps. Although these individuals have more experience in the classroom than the team that developed the camps, these teachers lack the exploration experiences and anecdotes offered by seagoing professionals that make the experience more real. To counter this inevitability, we have developed a series of videos that instructors can use to address a range of potential questions and to provide direct ties to actual operations.

An additional obstacle that researchers face in developing a summer camp is a general lack of financial support. We, however, have been fortunate in having several funding streams that made SSROV Camp a reality. Lastly, some of the new activities that were developed for the camp will be incorporated into the RETINA (Robotic Exploration Technologies IN Astrobiology) Program (Wheat et al. 2013) to provide options and/or additional materials for classroom teachers who wish to provide a more comprehensive program.

FIGURE 4. A team of campers describes their proposed research expedition to South Chamorro Seamount to an audience of fellow campers and their parents at the end of the week. South Chamorro Seamount is one of a dozen serpentinite mud volcanoes in the Mariana forearc. These are the largest mud volcanoes on Earth and fluids that discharge from them have a pH of 12.5, which is the pH of household bleach (Wheat et al. 2008). Courtesy of SSROV Camp
REFERENCES


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TREVOR FOURNIER is a graduate of California State University Monterey Bay with a bachelor of science degree in marine science. He has almost a decade of experience in sea-going operations, including the design and fabrication of numerous sensors and samplers.

KAREN MONAHAN is a graduate of the University of California, Irvine and obtained a teaching certificate through UC Berkeley Extension. She has a decade of teaching and editing experience.

CLAUDIA PAUL is a graduate of William and Mary with a bachelor of science degree in environmental science. She has worked in a laboratory for two decades on a plethora of sea-going projects.
Meet the Grays

BY EMILY WAGGONER AND DIEUWERTJE KAST

Thick fog swept down, enveloping the 24-foot Zodiac boat. Carrie frantically asked me to write down the G.P.S. coordinates of the buoy. I quickly wrote down the numbers and clasped the paper tightly in my hand. We hesitantly continued on to Gull Rock. The motor halted. Still squeezing the paper for comfort, I closed my eyes, concentrating on the sea’s symphony. Suddenly, a new instrument joined in, like a trumpet entering the string section. My eyelids parted to see a gray whale named McFlurry coming up for air, five feet from the Zodiac. I looked down to see my fingers relaxed, palms riddled with nail indentations. When McFlurry dove back into the water, I peered into her eye and smiled with ease. All my fears disintegrated and I folded the paper, placing it in my pocket and out of my mind.

Such encounters became an everyday affair during my summers with marine biologist Carrie Newell. Living in Depoe Bay, Oregon with Carrie introduced me to the life of a whale researcher. I was her right-hand woman, going out on the boat every day to photo identify a group of 80 resident gray whales, a species she has studied for over 20 years. Hours were spent going through the photos taken from that day, giving creative names to the new whales based on pigmented markings on their head, rostrum, and fluke.

– Emily Waggoner, on her experience with gray whales

ABSTRACT

With the help of Dieuwertje Kast, Emily Waggoner integrated her experience with gray whales and passion for digital visualizations to design Meet the Grays—a lesson plan that utilizes digital arts in order to spark a passion for marine science in K-5 classrooms. Despite being among the largest mammals on Earth, gray whales are not well understood and, like other marine education topics, unfortunately play a minimal role in elementary school science curricula. The goal of Meet the Grays is to transform these mysterious, 40-ton mammals into individuals with names and personalities for elementary students. Because whales can be difficult to visualize, students learn about the grays through two-dimensional (2D) animations, followed by an interactive activity focusing on gray whale migration through a cardboard model of the West Coast and three-dimensional (3D) printed gray whale characters. Through this lesson, students gain a better understanding of the species and are introduced to digital arts and 3D printing and, more importantly, build a connection to the mammals as individual creatures.

INTRODUCTION

Emily Waggoner, a research student at the University of Southern California (USC) and a Science, Technology, Engineering and Mathematics (STEM) intern for YSP, found her passion in the eye of a whale. Her fears of the depths of the ocean faded with one look, which catalyzed her desire to explore whales throughout the summer with marine biologist and professor at Lane Community College, Carrie Newell.

Students in Ms. Jasmine Tigolo’s fifth grade classrooms beta test the lesson plans. Courtesy of Dieuwertje Kast
Through this enriching experience, she gained a new-found faith in herself and discovered a passion to uncover and share the ocean’s complex beauty.

As Emily’s first female mentor, Carrie embodied the characteristics and scientific values that she admired. She emphasized hands-on learning with imaginative stories to better understand and remember everything from gray whale anatomy to feeding techniques. Since arriving at USC in 2014, Emily has continued to pursue her passion in studying marine research and education, incorporating both, a minor in science visualization and an internship with Dieuwertje “DJ” Kast, STEM programs manager of the USC Joint Educational Project and director of the Young Scientist Program (YSP) and Wonderkids Programs.

According to Kast, the YSP works in partnership with six USC community schools to engage more than 2000 elementary school students, 75 Los Angeles Unified School District (LAUSD) teachers, and six school principals through a broad repertoire of science curricula. YSP brings scientific laboratory experiences directly to students and their teachers with the goal of supplementing current science instruction, complementing LAUSD and state grade level science learning standards, strengthening science literacy, and promoting interest in scientific careers.

In addition to the goals mentioned, one of the primary objectives of YSP is to increase the number of science activities available to a larger group of neighborhood children to encourage them to consider careers in STEM, and to apply what they are learning in the classroom to the real world.

USC Wonderkids is one of those programs provided after school by USC ReadersPlus tutors at partnering schools (schools served varies each semester based on tutor availability and staffing) and offered twice each week to elementary students. The STEM curriculum for this program was designed to introduce first through third grade students in the afterschool program to the myriad of careers in the sciences and to promote a sense of curiosity about the many wonders of science. Various science fields are introduced in two-week blocks through literature and hands-on activities. The final lesson in each science field block is presented by guest speakers—professional scientists from each field of study. The scientists share more about their work, engage children in fun and exciting science activities so that they can “play scientist,” and answer any lingering questions children
may have about their work in the field. Some examples of science fields introduced are: neuroscience, environmental science, paleontology, deep sea, marine biology, botany, robotics, space, chemistry, DNA, animal behavior, and medicine.

As a way to become more involved with YSP and Wonderkids, Emily Waggoner started a STEM Internship last year, creating curriculum and resources about marine science. In the Spring of 2017, Dieuwertje and Emily applied for and received a grant through the National Marine Sanctuary Foundation for a marine science unit as part of the WonderKids programming. One of the four lesson plans introduced students to gray whales and was quickly transformed to Meet the Grays. This lesson introduced Emily’s second family, the Oregon resident gray whales, through digital arts and animation, bringing marine education concepts to a community of K-5 low-income students. Gray whale behaviors, hitch-hikers (whale lice and barnacles), and feeding mechanisms are taught through 2D animations to present digital technology and art integration. Real gray whales (identified by the names: Ice Cap, Blanco, Comet, Lucky, and Eagle Eye) are then introduced to students to show them how researchers identify grays in the wild. Once the students are familiar with the grays, they are then shown an interactive game on gray whale migration, which is introduced as a long trip from Alaska down the West Coast of North America to Baja Mexico. This game highlights the trials and adventures that a gray whale may face over their annual journey. The topics taught include: food availability, the group of grays (Summer Resident gray whales) who stay in Oregon rather than travel to Alaska, the journey with the addition of a calf (baby gray whale), and run-ins with boat propellers and killer whales. The game pieces are 3D printed whales of the five real individuals taught in the first half of the lesson, and baby whales which are scaled down to one-third of the size.

This became the highlight of Emily’s last semester at USC, integrating the lesson with her minor capstone project to build a marine science learning experience for not only Wonderkids, but to also be accessed by marine science and other educators. To beta test the lesson plan, additional funding was provided by Dr. Jane Goodall’s Roots and Shoots Mini grant program. Together, the two grants covered the cost of the materials needed for the curriculum, including 3D printing PLA, spray paint, a 2D animation drawing tablet, and other educational tools. The process of the game’s creation is detailed here for use by other educators.

**LESSON OVERVIEW: MEET THE GRAYS**

The students are introduced to whales and gray whales specifically, through a whale migration book and 2D animations. A migration game was created to expand upon Oregon’s resident gray whales. The goal of the game is to introduce students to the gray whale migratory patterns by physically taking a whale on the journey from Baja, Mexico to Alaska. A gray whale 3D model seen in the photo below is used as the game characters and printed on a 3D printer. Cardboard was used to form the board for the game, with elevated cut-outs of the West Coast. Spray paint was used as the finish on the board, and the action cards that the players move through were adhered to reflect a typical gray whales’ journey. Ultimately, four boards were created with the intention of five to seven students playing per game. The game was beta tested in Jasmine Tigolo’s fifth grade classroom at the Foshay Learning Center. A fifth grader named Delilah Rangel said, “I learned that on the gray whales back they have a lot of colorful bumps and white spots. Some of the whales are born with white spots (like freckles). Some of them get the white spots from little animals called barnacles.” Another student, Stephen Gomez said, “I thought the game was cool because of how Ms. Emily made the whales look real.”

Gray whale migration game: Far left is a photo of the gray whale model, followed by the 3D printed whales (second from left). The last three photos (from left to right) show the progression of making the board game, from cutting the cardboard to spray painting and attaching the game cards to the board. Courtesy of Emily Waggoner
This digital arts project has been documented on a blog* (see resources), step-by-step, from beginning to end so it can be replicated by teachers for their students. Beyond making the website publicly accessible, we hope to share the project with involved networks to increase visibility and impact. The website will be shared with Carrie Newell’s Whale Research EcoExcursions website, and USC’s Joint Educational Project (JEP) that work with 75 classrooms.

RESOURCES

Little Gray’s Great Migration:
https://www.amazon.com/Little-Grays-Great-Migration-Lindsey/dp/1628554606

Gray whale 3D model:
https://www.turbosquid.com/3d-models/maya-scan-grey-whale-maquette/594427

Deezmakers’ 3D printer: http://deezmaker.com/

Whale Keychain 3D model: https://www.thingiverse.com/thing:1689057/#files

Meet the Grays blog*: https://meetthegraysblog.wordpress.com/

Lesson Plan: http://www.meetthegrays.org/

Carrie Newell’s Whale Research EcoExcursions:
http://www.oregonwhales.com/oregonwhales2.html

EMILY WAGGONER is a senior at the University of Southern California, pursuing a bachelor of science degree in environmental studies and minor in science visualization. Looking forward, she hopes to integrate digital arts and marine science in her career, to expand her knowledge of and passion for the ocean.

DIEUWERTJE KAST focuses her work on creating STEM programs, providing professional development and mentorship, and supporting integrated STEM education throughout California. Through her efforts, she has provided STEM instruction to over 20,000 underrepresented minority students, 500 educators, 20 school principals, and countless members of the community. Kast has not only revitalized the Young Scientists Program (YSP), but also doubled the number of students and teachers served through the program.
Engaging High School Students and Teachers Through an Ocean-Observing Technology STEM Outreach Club

BY DR. JORDON BECKLER, KILEY GRAY, BEN CAROTHERS, HALLE FIELDS, BOB CURRIER, AND DR. RYAN SCHLOESSER

ABSTRACT
The Mote Ocean Technology Club, a new outreach program at Mote Marine Laboratory in Sarasota, Florida, implemented state-of-the-art technology to engage 12 high school students and four teachers during a semester-long afterschool STEM program. Club activities were broad and interdisciplinary, but the primary goal was to build inexpensive sensors and disseminate data streams to the Gulf of Mexico Coastal Ocean Observing System (GCOOS)—emulating the activities of many ocean-observing labs around the world. This article details club activities, provides links to the online curriculum, summarizes successes, challenges and recommendations for similar (or smaller) classroom-based efforts, and describes curriculum plans for the next phase of the club.

INTRODUCTION
The ocean-observing system enterprise offers an excellent opportunity to engage students in marine education activities that are integrated across multiple disciplines. Using existing data sets spanning physical, geological, chemical, and biological sciences, core oceanography concepts can be reinforced with real-world data. Students and teachers can participate in the end-to-end collaborative process between engineers, data providers, fisheries scientists, and regional ocean-observing systems to integrate their own "maker movement" sensors and platforms with a real-time communications ocean-observing infrastructure. Students develop a sense of ownership in their data streams and are exposed to a range of ocean-observing activities while gaining practical experience with many technology and marine science concepts. This article details how Mote Marine Laboratory scientists collaborated with the GCOOS to host an Ocean Technology Club, in which members designed electronic circuitry and programmed microcontrollers, prepared, deployed, and piloted an autonomous underwater vehicle (AUV) and a remotely operated vehicle (ROV), and had exciting discussions with Ph.D. scientists in ocean-observing based careers.

The advancement of regional and global ocean-observing systems over the past decade is largely dependent on the development of new and emerging sensor technologies and data integration capabilities. Combined, these enable the aggregation and integration of a myriad of data streams that support critical environmental, economic, safety, and scientific services. Autonomous in situ sensors are becoming rapidly more advanced and inexpensive, allowing chemical, physical, and biological measurements to be obtained remotely from fixed locations like buoys, pilings, and docks, as well as mobile platforms like ROVs, AUVs, and satellites (Perry et al. 2013; Shapiro et al. 2014). These sensors typically report regularly to host network systems that perform data management such as logging and filtering, and sometimes providing data to stakeholders and the public via web-accessible—analogous to a weather service for the ocean (Perry et al. 2015). In this manner, the ocean-observing system concept is one of a "system of systems" where information from nested sub-systems is aggregated and integrated, so that synergies and economies of scale are generated from nominal investment. The U.S. Integrated Ocean Observing System (IOOS) is the nation’s operational observing system and is comprised of 17 federal entities and 11 regional associations. Mote Marine Laboratory is a member of the regional coordinating entity for the Gulf of Mexico, the GCOOS. Another system, the Ocean Observing Initiative (OOI), supported by the National Science Foundation, is a cabled observatory focused on science investigations.

Traditionally, oceanographic sensors were the product of academic labs or their commercial spin-offs. Recent technological advances such as inexpensive, small, embedded computers with extensive programming libraries (e.g., Arduino, Raspberry Pi, Beaglebone); publicly accessible communications and location servicing satellites (e.g., GPS, Iridium, Argos); local communications (e.g., WiFi, Bluetooth, RF); and cloud computing (i.e. the “Internet of Things” or IoT) have truly democratized ocean observing.
While a list of potential configuration combinations is beyond the scope of this article, the most common configuration, the structure-mounted, fixed-location moored system, warrants a description. It has three main components:

- a power source to drive the system. This is usually a standard 12 V marine battery recharged by a simple solar panel and charge-controller system;
- a waterproof sensor with a built-in microcontroller responsible for obtaining readings; and
- a modem which accepts simple serial or Ethernet formatted data from the sensor and transmits it to a network.

Compared to the majority of oceanographic STEM outreach programs that focus on designing underwater vehicles, especially ROVs (e.g. MATE, SeaPerch), club participants focused on the fixed-location ocean-observing system because it offers several unique aspects not available with mobile platform programs. For example, the focus on oceanographic measurements, data storage and transfer, and power infrastructure provides multidisciplinary skills that are highly sought after in the job market. Activities of the club mimic and improve upon activities of the Mote Ocean Technology Research (OTR) program and other ocean-observing labs by developing low-cost, in situ, autonomous, remote oceanographic observation platforms complete with waterproof temperature sensors, solar power, communications, and near-real-time, web-accessible data. Moreover, the platforms are ready to accept additional sensors such as pressure, conductivity, barometric pressure, humidity, and many others.

CLUB STRUCTURE AND LOGISTICS

Meetings were hosted by three instructors in the Mote OTR program, including a scientist, electronics technician and computer science intern, and an instructor from the Mote Marine Laboratory Education program. Guest speakers and instructors were regular participants at the meetings. Club members consisted of 12 students and four teachers from a total of seven Sarasota and Manatee County high schools. Students were selected via a Google Forms application process. The form was distributed to technology or science coordinators at each school through the Mote Marine Laboratory Communications department, which resulted in reports from several media outlets (Delaney 2016). Thirty student applications were received. Selection was based on a combination of criteria, including maximizing the number of schools represented, student need and motivation based on application responses, and equal number of males and females. Seven applications were received from teachers. Selection of the four was based on their respective scheduling constraints.

During the inaugural semester from January 10 to April 18, 2017, participants met from 5:00 to 8:00 p.m. every other Tuesday. There were also two weekend field trips and several optional opportunities to participate in oceanographic field work.

Meetings were held in the Sarasota-Operations of the Coastal Ocean Observations Lab shared oceanographic operations and education center (SO-COOL; see Figure 1 on page 15). The center has four workstations with Apple computers that mirror displays to panel televisions mounted above for sharing progress. Custom-built sensor platforms were tested on campus at the Mote dock at New Pass; Sarasota Bay; and subsequently installed at multiple sites in Phillippi Creek, one of the primary freshwater inputs to Sarasota Bay. Site selection was based on the desire to co-located, student-built sensors with existing sensor arrays used to detect PIT-tagged juvenile snook (i.e. Passive Integrated Transponder) operated by the Mote Marine Laboratory Fisheries Ecology & Enhancement program.

Club members were invited to a private shutterfly.com page which was used to host slideshow lectures and homework, and for sharing program information such as announcements, discussions via a bulletin board, a club calendar with sign-ups for field trips, and photo sharing. To reinforce the concepts of open-source architecture, a club page on github.com was used to create and provide access to a step-by-step guide for constructing the custom sensor hardware and downloading and installing code. The goal for the inaugural semester of the Ocean Technology Club was to expose participants to the broad scope of the ocean-observing system enterprise, with emphasis on the importance of technology to create a comprehensive end-to-end system that spans research to operations. To achieve this, the curriculum was designed to take participants through the design of the platform infrastructure (physical and network), and then the installation of a temperature sensor on each platform (Agenda included as Appendix). Many of the activities require a significant investment in personnel and resources, so information here is presented primarily to only provide ideas for other clubs, workshops, or classroom activities.

NOTABLE ACTIVITIES

Low-cost sensor design: This activity takes approximately 16 hours to complete, so it is recommended for implementation in a long-term club or weekend workshop. A walkthrough of the platform and sensor design is available on the Mote Ocean Technology page on Github. The members were divided into four separate teams (four students and one teacher) and each group was responsible for building and
testing a sensor platform over the course of the first six sessions. As much as possible, each group participates in multiple activities simultaneously to ensure involvement by all team members. Once the sensor platform is constructed, temperature data are obtained and saved both locally on an SD card, and transmitted in real-time to a data server created by GCOOS and hosted on an Amazon Cloud instance (http://clouddev.mote.org/) using Wi-Fi hotspots (although any Wi-Fi connection can be used). Several sensors were installed at the Mote Marine Laboratory New Pass dock and Phillippi Creek by Mote Marine Laboratory staff as practice prior to the field trip with students. During this trip, one sensor was installed by members at another location in Phillippi Creek (see Figure 2 on page 16), co-located with an existing sensor platform designed to detect tagged juvenile snook; thus, providing an essential ancillary temperature data stream. (Note: A more simple temperature sensor and data-logger was designed and is also available on the Mote Marine Laboratory Github page.)

**Hypotheses and data treatment conception:** The students were informed about the data streams that would be generated from the fixed-location scientific instruments, including the type and format of data, the locations, and the frequency of sampling. Specific data streams anticipated included: the temperature from four sites measured every 10 minutes (upstream and downstream sites with vegetation present or absent); and the date, time, and identification number of an individual tagged fish when it swam over each of the associated detector arrays. Students were asked to create and share hypotheses on the shutterfly.com site (in null and alternative form) from the data streams and to think about how they could use the data to prove or disprove the hypotheses, including constructing mock time-series or co-variate plots. Moreover, they were taught the concepts of data-binning and extrapolation, especially important since our anticipated data streams were not going to be on the same timescales. Finally, it was stressed that under ideal circumstances, hypotheses are generated prior to implementing...
data collection tools; however, it is very often in science that the latter occurs, and hypotheses and results are “piggy-backed” from existing data streams.

“Journey” from breadboard to a printed circuit board (PCB): To illustrate how a manufactured circuit board is not an overwhelmingly complex “black box,” club members were exposed to the circuit board design process incrementally throughout the semester. This narrative was completed in the fifth session, when an oceanographic instrumentation engineer demonstrated how the breadboard components (Figure 2) could be taken to the next step using circuit component placement software (PCB Express); and then finally submitted electronically to a production company who delivers a PCB. Members were exposed to the entire spectrum of circuitry: 1.) working with an Arduino controlling an onboard LED (session one); 2.) Arduino controlling an LED on a solderless breadboard (session two); assembling all of their components onto a solderless breadboard in reality and using Fritzing simulation software (session four and as homework, respectively); soldering the boards into place on a through-hole breadboard (session five); and to finally, observing the creation of a PCB for production (session five).

Explore other IOOS: The members became familiar with GCOOS, the Gulf of Mexico regional association of IOOS, and some of the sensors that are in service and currently reporting. Once the students were more well-versed in the types of oceanographic measurements that can be obtained, it was an appropriate final club activity to ask them to choose another regional association as a group and to summarize the oceanographic operations occurring in that area—a task that they would not have been able to properly complete prior to the club. Groups were tasked to pick an IOOS regional
FIGURE 3. Temperature measurements of the bottom water at the Phillippi Creek site PL2 from the sensor installed by the club members, and depth measurements at a NOAA buoy in Naples for comparison. The temperature measurements are generally in sync with the tide measurements, and this time series plot offered an excellent discussion opportunity for the club. Courtesy of Mote Marine Laboratory

ASSESSMENT

The Ocean Technology Club successfully used technology as a tool to excite students about the ocean. An exit poll was provided via Google forms. From the exit poll, it was clear that members learned technical skills that could be objectively quantified (see Figure 4 on page 18). However, two of the nine responses (students and teachers) concluded that more practice in these skills was needed. Also, from the student responses, five were more likely to pursue STEM careers, two had unchanged opinions and were already planning STEM careers, and none of the students were dissuaded from STEM careers.

Open-ended exit poll questions were generally positive. When asked about their favorite activities, responses were enthusiastic and quite varied: four for sensor design, four for the installation, and three for the guest speakers. (Note: some members described multiple favorites so there were more than nine responses.) One member appreciated the holistic approach to describing all facets of the creation of an oceanographic sensor. On the other hand, the curriculum was ambitious for eight meetings and, while the activities were exceptionally well-received, not all goals were met. For instance, only three of the four sensors were installed in the field, but they were not necessarily transmitting data simultaneously so members’ hypotheses could not be evaluated. Two students commented that the biweekly meetings were not frequent enough; however, one would have preferred shorter meetings. Two comments on the exit survey indicated that there were more hands-on experiences needed,
and two students requested more homework in order to prepare for the club topics in advance.

Also worth mentioning, are the broader impacts of the club, including the experience gained by two Ocean Technology Research interns. The designer of the club sensors and platforms subsequently obtained internships at the Federal Reserve Bank and then Google, and she credits her experience building sensors at Mote as her primary introduction into hardware and software design. In session 10, we connected with her via video chat and she shared her experience and gave recommendations to the club members. The intern who helped with the execution of the club recently obtained a job with Wevolver, Inc., a company similar to GitHub, Inc. that focuses more on open-source hardware projects. We plan on using Wevolver to disseminate the sensors that will be constructed in the next semester of the club.

**FUTURE PLANS**

We do not plan on repeating the same curriculum as described here in the next semester of the club. We hope to retain approximately half of the members and then seek additional students with more diverse backgrounds, while increasing the total members of the club from 16 to 20. Feedback from teachers during the solicitation process indicates that underrepresented students might be intimidated by the application process and appearances in person to solicit club members may be necessary. Indeed, in-person experiences by Dr. Beckler did increase the number of applicants from the respective schools. Summer reading will be prescribed and stricter homework policies during the semester will be instituted to aid in participants’ comprehension of club activities.

To provide more hands-on practice at soldering, circuit design, and coding in the next semester of the club, each student will be responsible for the construction of their own sensor, instead of constructing one sensor per group. In turn, we have currently partnered with a nearby company, Loggerhead Instruments, Inc., who is helping guide the design of new state-of-the-art tags for large fish. These tags will improve upon Loggerhead’s existing “openTag,” which measures motion parameters, depth, and temperature and stores data on a flash card. Now, each of the 20 students will construct their own sensor with all the sensing capabilities of the openTag—but with improved power and communications and, in turn, a sleeker custom 3-D printed housing—allowing use with fish smaller than the traditional targets of dolphins and turtles. Club meetings will be held at Mote Marine Laboratory on weekdays, but weekend workshops will be held at the nearby Suncoast Science Center / Faulhaber Fabrication Lab where the actual sensor construction will take place. This will offer the advantage of a larger workspace for sensor construction and access to 3-D printers. Once completed, these sensors will be used...
by Mote’s fisheries researchers who will attach them to goliath grouper at a reef to study their spawning behavior. The guest lecture on the topic of using hydrophones for fish detection (Dr. Jim Locascio) was very well received, so we expect the fish tag activity will be exciting for club members. Also, based on exit survey results, the sensor as designed was too difficult for some members who had no prior programming knowledge. The new fish tag sensors are less code intensive, as they rely on existing Arduino-compatible libraries. Additionally, partnering with Loggerhead Instruments will allow us to expand the earlier described, “Journey from breadboard to PCB.” Club members will be able to observe a “pick and place” machine that will build their PCB and place the components; thus, completing the “journey” by producing the entire sensor in-house, including a permanent, robust PCB board, instead of the existing curriculum in which the boards would have been sent away for production.

ACKNOWLEDGEMENTS
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RESOURCES
• Integrated Ocean Observing System (IOOS): http://ioos.noaa.gov/
• Ocean Observatories Initiative: http://oceanobservatories.org/
• Mote Marine Lab & Aquarium: http://mote.org
• Arduino: https://www.arduino.cc/
• GCOOS Data Portal: http://gcoos2.tamu.edu/gandalf/
• Mote Marine Lab Data: https://github.com/MoteMarine/
• Mote Marine Lab Data: http://coolcloud.mote.org/socool_hab/home
• The Cave Pearl Project: https://hackaday.io/project/6961-the-cave-pearl-project
• Loggerhead Instruments: http://www.loggerhead.com/opentag-motion-datalogger
• Suncoast Science Center: http://www.suncoastscience.org/
• Wevolver: https://www.wevolver.com/

REFERENCES


APPENDIX
Meeting Agenda
• Club overview with parents
• Icebreakers
• Introduction to Mote Marine Laboratory and Ocean Technology Program
• Introduction to Arduino microcontroller programming (built-in Arduino “Blink” example program) and electronic circuit no-solder breadboards
• Introduction to electronics and circuits
• Temperature sensor soldering to Arduino
• Introduction to code writing
• Introduction to open-source design and Github
• Controlling components external to the Arduino (built-in Arduino “Blink 2” program)
• Assemble temperature sensor underwater housing and circuit (part 1)
• Program and test the temperature sensor
• Configure (i.e. program) the SD card reader, and real-time clock components
• Guest speaker: Fisheries biologist about fish tagging
• Assembly and testing of individual components on the solder-less breadboard
• Enclose temperature sensor assemblies in epoxy

• Guest speaker: Oceanographic Instrumentation Engineer about the path to a printed circuit board (PCB) from a breadboard
• Demonstration of Mote OTR red-tide monitoring equipment
• Solder all components to permanent breadboard
• Demonstrate Fritzing.org software

• Hands-on experience piloting a Remotely Operated Vehicle (openROV)
• Install first temperature sensor as a group at the Mote Marine Laboratory dock in New Pass
• Assemble solar power circuit

• (Saturday Field Trip): Field trip to Phillippi Creek (site “PL2”) to install a sensor, and the battery and communications infrastructure
• Fisheries scientist demonstrates fish PIT tag detection arrays
• Hands-on activity flying drone

• Guest speaker: Fisheries scientist about acoustic hydrophones for fish
• GCOOS Data Engineer about life as a data scientist with GCOOS and the web-based infrastructure of club sensors and routing of sensor data

• (Saturday Field Trip): Field trip to Suncoast Science Center / Faulhaber Fab Lab for demonstration of machining tools, i.e. the equipment used to make the above-water housing for the sensors

• Guest speaker (skype): Former OTR intern for career guidance
• Demonstration of Mote’s AUV in ballast tank
• Pizza party on dock
• Sensor data discussion
• Integrated Ocean Observing Systems (IOOS) Regional Association research and discussion activity

DR. JORDON BECKLER is currently an assistant research professor in the Geochemistry and Geochemical Sensing Lab at the Harbor Branch Oceanographic Institute, Florida Atlantic University. This work was performed while he was the program manager for the Ocean Technology Research Lab at Mote.

KILEY GRAY earned her bachelor’s degree in marine biology from the University of West Florida and is currently an educator at Mote. She managed the club logistics and assisted with lecture design.

BEN CAROTHERS is currently a software engineer at Wevolver. He completed the sensor design and Github site while an intern at Mote and undergraduate student at the New College of Florida.

HALLE FIELDS is a University of Miami undergraduate studying computer science, mathematics, and business technology. She designed the original version of the sensors while a Mote intern.

BOB CURRIER is a GCOOS research specialist in the Department of Oceanography, Texas A&M University. His primary area of expertise is ocean observation data management and visualization.

DR. RYAN SCHLOESSER is a post-doctoral scientist in the Fisheries Ecology and Enhancement program at Mote. He assisted with the field portion of this research.
Film Series Spawns Teen Ocean Stewards

BY KIMBERLY WILLIAMS

Our oceans are at a critical turning point as they face intense pressures from increasing industrial uses, pollution, ocean acidification, and sea level rise. In some regions of the United States, collaborative planning for the future of our oceans is bringing together state and federal agencies, Native American tribes, and stakeholders from a variety of sectors. Teaching students about important marine policy decisions being made right now is vital for them to become informed ocean stewards. In my high school classroom in Smithtown, New York, I’ve been using the Ocean Frontiers film series to encourage students to think about the ocean in a new way and inspire them to take action. The ocean connects all subjects and age levels, and we, as teachers and educators, need to help students learn to stay alert and engaged.

I have a student-centered, inquiry-based approach to teaching and try to incorporate relevance to my student’s lives whenever possible. Our best days as a class are when I’ve brought them to the brink of a new world, concept, creature adaptation, or way of looking at things—and let them stumble upon ideas, solutions, etc., as if they were the first ones on Earth to experience it! When I see them so inspired that they run out of the room when the bell rings, still busy arguing a point or imagining a new idea, that’s a successful day to me. Without a doubt, successful ocean steward building involves having a wide variety of “tools” to help students get to that point. The Ocean Frontiers film series provides a website and curriculum guides to help educators develop new ways to incorporate teaching tools, including lesson plans, films, video clips, blog posts, and ocean action items, into classroom activities.

The four films in the award-winning series show how collaborative, science-based ocean planning can benefit coastal communities, the economy, and the ocean (Sidebar 1 on page 22). Produced by Green Fire Productions, the films delve into the question: How do we meet our ever-expanding demands on the ocean without destroying it? With the Northeast and Mid-Atlantic regions in the U.S. now implementing their new regional ocean plans—and the West Coast beginning their planning process—I find it incredibly timely to teach about our busy oceans.

Oceanography students learning taxonomy, safe crustacean handling, and career options they saw in the Ocean Frontiers films. Courtesy of Kimberly Williams
I started using these films in 2013, shortly after the first installment, *Ocean Frontiers: The Dawn of a New Era in Ocean Stewardship* was released. The film has four chapters, with each segment focusing on unlikely allies working together to address an ocean-related challenge in their part of the country, from changing the shipping lanes in Boston Harbor and protecting endangered whales, to Iowa farmers creating wetlands to reduce deadly fertilizer runoff into the Gulf of Mexico. An educator’s resource guide for middle and high school teachers and a discussion guide for university professors are available for this film.

My marine ecology and oceanography courses (for high school and college credit) are where I showed the original *Ocean Frontiers* film. Students’ comments ranged from, “Wow, I can’t believe all the different jobs a person who loves the ocean can actually do,” “Thanks for not showing us such doom and gloom stuff,” to “If it were me, I’d do this...”. Their reactions to the film lead to engaging classroom discussions geared exactly in the direction we want them to go, which is to use appropriate vocabulary to make educated decisions about our shared resources. These types of discussions then prepare them for when they have opportunities to write to or speak with elected officials in our community.

*Ocean Frontiers II: A New England Story for Sustaining the Sea* tells the story of New England’s efforts to create an ocean plan for the entire region. The film focuses in on an offshore wind energy development and their collaboration with fishermen, Native Americans, and conservationists that became possible through the Rhode Island state ocean plan.

My colleagues and I planned an activity using this film that involves us organizing the students into groups and asking them to be the planners who create a pilot for an offshore wind farm. Then we ask them to come up with plans and discuss their plans among their peers, including accountability to all user groups. After the exercise, we show them the film and have a productive discussion about who thought to involve each of the user groups mentioned in the film. The students are always amazed about the possibility of an underwater burial ground that includes Native American tribes as one of the user groups.

The latest installment in the series, *Ocean Frontiers III: Leaders in Ocean Stewardship & the New Blue Economy* is a powerful film that chronicles U.S. efforts to plan for a healthy, safe, and sustainable future for our oceans. It explores the intersection of national security, maritime commerce, fishing, and recreation, plus expanding industries such as offshore wind energy and aquaculture, coupled with scientific

**SIDEBAR 1. FILM DESCRIPTIONS AND LINKS**

Teachers can order the films free of charge at [http://ocean-frontiers.org/host-a-screening](http://ocean-frontiers.org/host-a-screening).

**Ocean Frontiers III: Leaders in Ocean Stewardship & the New Blue Economy**

Chronicles recent efforts along the Eastern seaboard to plan for a healthy, safe, and sustainable future for our oceans. (55-minute film, plus excerpts and short clips)

- **Trailer:** [http://ocean-frontiers.org/the-films/ocean-frontiers-3](http://ocean-frontiers.org/the-films/ocean-frontiers-3)

**Ocean Frontiers II: A New England Story for Sustaining the Sea**

In a pioneering trial of ocean planning, people are coming together to keep their ocean and livelihoods alive. (45- and 28-minute versions available)

- **Trailer:** [http://ocean-frontiers.org/trailer](http://ocean-frontiers.org/trailer)

**Ocean Frontiers: The Dawn of a New Era in Ocean Stewardship**

Journey to coral reefs, seaports, and watersheds across the US, where unlikely allies are working together to sustain the sea and our ocean economies. (22-, 60-, and 80-minutes, aquarium and Spanish versions available)

- **Chapter clips:** [http://ocean-frontiers.org/the-films/ocean-frontiers](http://ocean-frontiers.org/the-films/ocean-frontiers)
- **Educator Guides:** [http://ocean-frontiers.org/discussion-guides](http://ocean-frontiers.org/discussion-guides)

**The Great Bear Sea: Reflecting on the Past–Planning for the Future**

Learn about the marine plans for British Columbia’s North Pacific coast where whales, wolves, bears, and humans thrive in rich coastal ecosystems. (60- and 75-minute versions available)

- **Trailer:** [http://ocean-frontiers.org great-bear-sea-trailer-2-min](http://ocean-frontiers.org great-bear-sea-trailer-2-min)
- **Curricula:** [http://greatbearsea.net](http://greatbearsea.net)
Marine ecology student using tools of the trade, the refractometer, to help appreciate salinity changes in our local tidal river. Courtesy of Kimberly Williams

discovery. Ocean Frontiers III debuted in 2017, and I use the film as an introduction to an activity modeled after the television show “Shark Tank.” Students devise an ad campaign to “sell” some component of how humans are sustainably using the ocean such as with offshore wind, aquaculture, ferry boat transportation, etc. Volunteer judges (or “Sharks”) then award students with pretend advertising dollars based upon the student’s understanding of how humans are sustainably using the oceans as well as the creativity of their ad campaign.

The new ocean plans rely heavily on the regional ocean data portals that are also demonstrated in the film. These online mapping tools are an excellent resource for teachers and students (see Sidebar 2). Using actual data not only makes what we do more meaningful to students, it is also an important component of the Next Generation Science Standards (NGSS), which emphasizes that students become proficient in predicting, engineering, modelling, and then analyzing results. This school year I plan to work with colleagues to use the data portals to create fun, engaging activities. For example, students can be presented with a real-life situation to examine and then work in small groups to create their own maps with data layers specific to that particular example.

What a great professional development opportunity it would be to have the Ocean Frontiers curriculum developers and regional ocean portal team members give an NMEA annual conference workshop about all the amazing things students can do using the data portals! For teachers interested in using Ocean Frontiers III in the classroom, a discussion guide for this latest film—for middle, high school, and college level courses—is in development and should be available in Fall 2018.

In addition to the three films about ocean planning in US waters, the filmmakers produced The Great Bear Sea: Reflecting on the Past-Planning for the Future, which is about recent marine planning efforts in Canada involving First Nations and the Province of British Columbia. There are so many fantastic, ready-to-use activities for elementary, secondary, and post-secondary educators on the website, but since my students and I have a soft spot for otters, I especially loved showing my students the Otter Kelp Research video clip in the Great Bear Sea Case Studies. When we covered vocabulary and concepts related to food webs and predator-prey interactions, I asked the students to view the short video at home and come back to class ready to discuss: a.) what the scientists are doing in the video; b.) how students would set up a similar research study in the area where we live; and c.) how the study teaches us the value of healthy ecosystems. After that discussion, I asked them to watch any of the other case studies and write answers to the same three discussion questions.

SIDEBAR 2. DATA PORTAL LINKS
West Coast Ocean Data Portal: http://portal.westcoastoceans.org
The videos are easily accessible to all students, visually beautiful, and short enough to keep the students engaged and asking questions. Once I knew they had watched and discussed all the clips, it was a perfect segue into Lesson 3 (page 49 of the free downloadable curriculum guide). We organized the students into groups and asked each group to research and be ready to report on the questions asked in the curriculum guide, as well as present any questions that arose in their group during their research. Since there are so many learning styles in the classroom, questions and comments from students provide a wide and diverse opportunity for an exchange of thoughts.

There is a reason that every type of student wants to participate in our school’s marine science courses, and I owe a great debt to people like the producers of the Ocean Frontiers film series who create content that help teachers reach different learner types. For students, it’s simple—they live on a planet of islands and they feel connected to it, even if they don’t know it yet! I take it as my personal mission to help every student find and develop their inner ocean steward, so I have absolutely come to rely upon the types of materials offered by the Ocean Frontiers staff. If your school doesn’t have a marine science program, this film series can support any existing environmental or ecological curricula.

There has never been a better time to ensure that students understand the role they play in caring for the ocean, whether it touches their own shores or other bodies of water around the planet. Now, more than ever, we owe it to our students to make sure they have seen what a difference working together and sharing solutions from around the globe have made for people from all walks of life like those introduced in the Ocean Frontiers film series. From farmers in Iowa to fishers in Oregon, scientists in Massachusetts to First Nations People in British Columbia, and yes, even to students in our classrooms, who are learning how to succeed in becoming our next generation of ocean stewards—our oceans connect us all.

KIMBERLY WILLIAMS has her master of science degree in marine environmental science and is also certified in earth science, biology, and general science, grades 5-12. In addition to fun-filled summers and weekends of fieldwork, she has enjoyed teaching marine science for over 20 years to students of all ages, but her primary audience is her high school oceanography and marine ecology “Squiddos.” Her students at Smithtown High School in New York can take her courses for college credit through the School of Marine and Atmospheric Sciences at SUNY Stony Brook and participate in many field experiences throughout the year.

Long Island Sound Science and Use students conducting water quality tests to compare pristine areas to those more visibly impacted by humans. Courtesy of Kimberly Williams
Supporting Conceptual Understanding of the Coriolis Force Through Laboratory Experiments

BY DR. MIRJAM S. GLESSMER AND PIERRÉ D. DE WET

Do intriguing phenomena sometimes capture your attention to the extent that you need to figure out why they work differently than you expected? What if you could get your students hooked on your topic in a similar way?

Wanting to comprehend a central phenomenon is how learning works best, whether you are a student in a laboratory course or a researcher going through the scientific process. However, this is not how introductory classes are commonly taught. At university, explanations are often presented or developed quickly with a focus on mathematical derivations and manipulations of equations. Room is seldom given to move from isolated knowledge to understanding where this knowledge fits in the bigger picture formed of prior knowledge and experiences. Therefore, after attending lectures and even laboratories, students are frequently able to give standard explanations and manipulate equations to solve problems, but lack conceptual understanding (Kirschner and Meester 1988): students might be able to answer questions on the laws of reflection, yet not understand how a mirror works, i.e. why it swaps left-right but not upside-down (Bertamini et al. 2003).

Laboratory courses are well suited to address and mitigate this disconnect between theoretical knowledge and practical application. However, to meet this goal, they need to be designed to focus specifically on conceptual understanding rather than other, equally important, learning outcomes: learning about the scientific process or understanding the nature of science, practicing experimental skills like observation, communicating about scientific content and arguing from evidence, and changing attitudes (e.g. Feisel and Rosa 2005; NGSS 2013; Kirschner and Meester 1988; White 1996). One learning outcome is often desired, yet for many years it has rarely been achieved: increasing conceptual understanding (Kirschner and Meester 1988; Milner-Bolotin et al. 2007). Under general dispute is whether students learn from watching demonstrations and conducting lab experiments, and how learning can be best supported (Kirschner and Meester 1988; Hart et al. 2000).

There are many reasons why students fail to learn from demonstrations (Roth et al. 1997). For example, in many cases separating the signal to be observed from the inevitably measured noise can be difficult, and inference from other demonstrations might hinder interpretation of a specific experiment. Sometimes students even “remember” witnessing outcomes of experiments that were not there (Milner-Bolotin et al. 2007). Even if students’ and instructors’ observations were the same, this does not guarantee congruent conceptual understanding, and conceptual dissimilarity may persist unless specifically addressed. However, helping students overcome deeply rooted notions is not simply a matter of telling them which mistakes to avoid. Often, students are unaware of the discrepancy between the instructors’ words and their own thoughts and hear statements by the instructor as confirmation of their own thoughts, even though they might in fact be conflicting (Milner-Bolotin et al. 2007).

HOW STUDENTS LEARN FROM LABORATORY EXPERIMENTS

In introductory-level college courses in most Science, Technology, Engineering, and Mathematics (STEM) disciplines, especially in physics-based ones like oceanography or meteorology and all marine sciences, laboratory courses featuring demonstrations and hands-on experiments are traditionally part of the curriculum.

Laboratory courses can serve many different and valuable learning outcomes: learning about the scientific process or understanding the nature of science, practicing experimental skills like observation, communicating about scientific content and arguing from evidence, and changing attitudes (e.g. Feisel and Rosa 2005; NGSS 2013; Kirschner and Meester 1988; White 1996). One learning outcome is often desired, yet for many years it has rarely been achieved: increasing conceptual understanding (Kirschner and Meester 1988; Milner-Bolotin et al. 2007). Under general dispute is whether students learn from watching demonstrations and conducting lab experiments, and how learning can be best supported (Kirschner and Meester 1988; Hart et al. 2000).

There are many reasons why students fail to learn from demonstrations (Roth et al. 1997). For example, in many cases separating the signal to be observed from the inevitably measured noise can be difficult, and inference from other demonstrations might hinder interpretation of a specific experiment. Sometimes students even “remember” witnessing outcomes of experiments that were not there (Milner-Bolotin et al. 2007). Even if students’ and instructors’ observations were the same, this does not guarantee congruent conceptual understanding, and conceptual dissimilarity may persist unless specifically addressed. However, helping students overcome deeply rooted notions is not simply a matter of telling them which mistakes to avoid. Often, students are unaware of the discrepancy between the instructors’ words and their own thoughts and hear statements by the instructor as confirmation of their own thoughts, even though they might in fact be conflicting (Milner-Bolotin et al. 2007).
Prior knowledge can sometimes stand in the way of understanding new scientific information when the framework in which the prior knowledge is organized does not seem to organically integrate the new knowledge (Vosniadou 2013). The goal is; however, to integrate new knowledge with pre-existing conceptions, not build parallel structures that are activated in context of this class but dormant or inaccessible otherwise. Instruction is more successful when in addition to having students observe an experiment, they are also asked to predict the outcome before the experiment and discuss their observations afterwards (Crouch et al. 2004). Similarly, Muller et al. (2007) find that even learning from watching science videos is improved if those videos present and discuss common misconceptions, rather than just presenting the material textbook-style. Dissatisfaction with existing conceptions and the awareness of a lack of an answer to a posed question are necessary for students to make major changes in their concepts (Kornell 2009; Piaget 1985; Posner et al. 1982). When instruction does not provide explanations that answer students’ problems of understanding the scientific point of view from the students’ perspective, it can lead to fragmentation and the formation of synthetic models (Vosniadou 2013).

One operationalization of a teaching approach to support conceptual change is the elicit-confront-resolve approach (McDermott 1991), which consists of three steps: eliciting a lingering misconception by asking students to predict an experiment’s outcome and to explain their reasons for the prediction; confronting students with an unexpected observation which is conflicting with their prediction; and finally, resolving the matter by having students come to a correct explanation of their observation.

**HOW STUDENTS TRADITIONALLY LEARN ABOUT THE CORIOLIS FORCE**

The Coriolis force is essential in explaining formation and behavior of ocean currents and weather systems we observe on Earth. It thus forms an important part of any instruction on oceanography, meteorology, or climate sciences. When describing objects moving on the rotating Earth, the most commonly used frame of reference would be fixed on the Earth, so that the motion of the object is described relative to the rotating Earth. The moving object seems to be under the influence of a deflecting force—the Coriolis force—when viewed from the co-rotating reference frame. Even though the movement of an object is independent of the frame of reference (the set of coordinate axes relative to, which the position and movement of an object is described, is arbitrary and usually made to simplify the descriptive equations of the object), this is not immediately apparent. Temporal and spatial frames of reference have been described as thresholds to student understanding (Baillie et al. 2012; James 1966; Steinberg et al. 1990). Ever since its first mathematical description in 1835 (Coriolis 1835), this concept is most often taught as a matter of coordinate transformation, rather than focusing on its physical relevance (Persson 1998). Most contemporary introductory books on oceanography present the Coriolis force in that form (cf. e.g. Cushman-Roisin 1994; Gill 1982; Pickard 1983; Talley et al. 2001; Tomczak and Godfrey 2003; Trujillo and Thurman 2013). The Coriolis force is therefore often perceived as “a mysterious’ force resulting from a series of ‘formal manipulations’” (Persson 2010). Its unintuitive and seemingly un-physical character makes it difficult to integrate into existing knowledge and understanding, and “even for those with considerable sophistication in physical concepts, one’s first introduction to the consequences of the Coriolis force often produces something analogous to intellectual trauma” (Knauß 1978).

In many courses, helping students gain a deeper understanding of rotating systems, especially the Coriolis force, is approached by presenting demonstrations, typically of a ball being thrown on a merry-go-round, showing the movement simultaneously from a rotating and a non-rotating frame (Urbano and Houghton 2006), either in the form of movies or simulations, in the lab as demonstrations, or as a hands-on experiment. After conventional instruction that exposed students to discussions and simulations, students were able to do calculations related to the Coriolis force.

Nevertheless, when confronted with a real-life situation where they are not part of the rotating system, students show difficulty in anticipating the movement of an object on a rotating body. In a traditional Coriolis experiment (see Figure 1 on page 27); for example, a student launches a marble from a ramp on a rotating table (see Figures 2A and B on page 27) and the motion of the marble is observed from two vantage points: where they are standing in the room, (i.e. outside of the rotating system of the table; and on a screen that displays the table, as captured by a co-rotating camera mounted above it). When asked, before the experiment, what path the marble on the rotating surface will take, students report that they anticipate observing a deflection—its radius depending on the rotation’s direction and rate. After observing the experiment, students report that they saw what they expected to see even though it never happened. Contextually triggered, knowledge elements are invalidly applied to seemingly similar circumstances and lead to incorrect conclusions (DiSessa and Sherin 1988; Newcomer 2010). This synthetic model of always expecting to see a
THE TRADITIONAL CORIOLIS EXPERIMENT

Students observing a metal marble launched on a rotating table are observing its path from where they are standing in the room (i.e. outside of the rotating system of the table; and on a screen that displays the table, as captured by a co-rotating camera mounted above it). Students are subsequently asked to:

- trace the trajectory seen on the screen on a transparency (Figure 2C on right);
- measure the radius of this drawn trajectory; and
- compare the drawn trajectory’s radius to the value calculated from the measured rotation rate of the table and the linear velocity of the marble, determined experimentally beforehand.

Target Group:
Any course, probably at college or university level, dealing with the Coriolis force.

Learning Objectives:
The student will be able to predict the trajectory of a moving body in different frames of reference.

Materials:
- Rotating table with a co-rotating video camera (Figure 2 on right).
- Screen where images from the camera can be displayed
- Marbles
- Ramp to launch the marbles
- Tape to mark positions on the floor
- Transparencies and markers
- Ruler and stopwatch

Time:
About 30 minutes per student group (maximum 5 students per group to ensure active participation by every student)
deflection of an object moving on a rotating body, no matter which system of reference it is observed from, needs to be modified for students to productively work with the concept of the Coriolis force.

Despite these difficulties in interpreting the observations and understanding the underlying concepts, rotating tables recently experienced a rise in popularity in undergraduate oceanography instruction (Mackin et al. 2012) as well as outreach to illustrate features of the oceanic and atmospheric circulation (see for example, Marshall and Plumb 2007). This makes it even more important to consider what students are learning from such demonstrations or experiments, and how these learning outcomes can be achieved.

A RE-DESIGNED HANDS-ON INTRODUCTION TO THE CORIOLIS FORCE

The traditional Coriolis experiment, featuring a body on a rotating table, observed both from within and from outside the rotating system can easily be modified to support conceptual understanding.

When students of oceanography are asked to do a “dry” experiment (in contrast to a “wet” one with water in a tank on the rotating table) on the Coriolis force, at first, this does not seem like an interesting phenomenon to students because they believe they have learned about it from lecture. The experiment quickly becomes intriguing when a cognitive dissonance arises and the students’ expectations do not match their observations. We use an elicit-confront-resolve approach to help students observe and understand the seemingly conflicting observations made from inside versus outside of the rotating system (Figure 3). To aid in making sense of their observations in a way that leads to conceptual understanding the three steps: elicit, confront, and resolve are described here.

1. What do you think will happen? Eliciting a (possibly) lingering misconception

Students are taught in introductory lectures that any moving object in a counter-clockwise rotating system (i.e. in the Northern Hemisphere) will be deflected to the right. They are also aware that the extent to which the object is deflected depends on its velocity and the rotational speed of the reference frame. In our experience, due to prior learning, students expect to see a Coriolis deflection even when they observe a rotating system “from the outside.” When the conventional experiment is run without going through the additional steps described here, students often report having observed the (non-existent) deflection.

![FIGURE 3. Positions of the ramp and the marble as observed from above in the non-rotating (top) and rotating (bottom) case. Time progresses from left to right. In the top plots, the positions are shown in inert space. From left to right, the current positions of the ramp and marble are added with gradually darkening colors. In the bottom plots, the ramp stays in the same position relative to the co-rotating observer, but the marble moves, and the current position is always displayed with the darkest color.](image-url)
By activating this prior knowledge and discussing what students anticipate observing under different conditions before the actual experiment is conducted, the students’ insights are put to the test. This step is important, since the goal is to integrate new knowledge with pre-existing conceptions; not build parallel structures that are activated in context of this class, but dormant or inaccessible otherwise. Sketching different scenarios (Fan 2015; Ainsworth et al. 2011), and trying to answer questions before observing experiments support the learning process, since students are usually unaware of their premises and assumptions (Crouch et al. 2004).

We, therefore, ask students to observe and describe the path of a marble being radially launched from the perimeter of the circular, non-rotating table by a student standing at a marked position next to the table, the “launch position.” The marble is observed rolling toward and over the center point of the table, dropping off the table diametrically opposite from the position it was launched. A second student—the catcher—is asked to stand at the position where the marble dropped off the table’s edge, so as to catch the marble in the non-rotating case. The position is also marked on the floor with tape to document the observation.

Next, the experimental conditions of this thought experiment (Winter 2015) are varied to reflect on how the result depends on them. The students are asked to predict the behavior of the marble once the table is put into slow rotation. At this point, students typically enquire about the direction of rotation and, when assured that “Northern Hemisphere” counter-clockwise rotation is being applied, their default prediction is that the marble will be deflected to the right. When asked whether the catcher should alter their position, the students commonly answer that the catcher should move some arbitrary angle, but typically less than 90 degrees, clockwise around the table. The question of the influence of an increase in the rotational rate of the table on the catcher’s placement is now posed. “Still further clockwise,” is the typical answer. This then leads to the instructor asking whether a rotational speed exists at the point where the student launching the marble, will also be able to catch it themselves. Usually the students confirm that such a situation is indeed possible.

2. Did you observe what you expected to see?
Confronting the misconception
After “eliciting” student conceptions, the “confront” step shows the students the discrepancy between what they expect to see, and what they actually observe. Starting with the simple, non-rotating case, the marble is launched again and the nominated catcher, positioned diametrically across from the launch position, seizes the marble as it falls off the table’s surface in front of them. As theoretically discussed beforehand, the table is then put into rotation at incrementally increasing rates, with the marble being launched from the same position for each of the different rotational speeds. It becomes clear that the catcher can—without any adjustment to their position—remain standing diametrically opposite to the student launching the marble at the point where the marble drops to the floor. Students then realize that the movement of the marble relative to the non-rotating laboratory is unaffected by the table’s rotation rate.

This observation appears counterintuitive, since the camera, rotating with the system, shows the curved trajectories the students had expected; segments of circles with decreasing radii as the rotation rate increases. Furthermore, to add to the confusion, when observed from their positions around the rotating table, the path of the marble on the rotating table appears to show a deflection too. This is due to the observer’s eye being fooled by focusing on features of the table, (e.g. marks on the table’s surface or the bars of the camera scaffold, relative to what the marble does, follows a curved trajectory). To overcome this optical illusion, the instructor may ask the students to crouch, diametrically across from the launcher, so that their line of sight is aligned with the table’s surface (i.e. at a zero-zenith angle of observation). From this vantage point, the marble is observed moving in a straight line towards the observer, irrespective of the rotation rate of the table. Observing from different perspectives and with focus on different aspects (Is the marble coming directly towards me? Does it fall on the same spot as before? Did I need to alter my position in the room at all?), helps students gain confidence in their observations.

To solidify the concept, the table may again be set into rotation. The launcher and the catcher are now asked to pass the marble to one another by throwing it across the table without it physically making contact with the table’s surface. As expected, the marble moves in a straight line between the launcher and the catcher, whom are both observing from an inert frame of reference. However, when viewing the playback of the co-rotating camera that views from the rotating frame of reference, the trajectory is observed as curved.

3. Do you understand what is going on?
Resolving the misconception
Misconceptions that were brought to light during the “elicit” step, and whose discrepancy with observations was made clear during the “confront” step, are finally resolved in this step. While this sounds easy, in practice it is not. For
learning purposes, the instructor needs to aid students in reflecting upon and reassessing previous knowledge. By dispelling any remaining implicit assumptions, the instructor points out that the discrepant trajectories are undoubtedly the product of viewing the motion from different frames of reference. Despite the students’ observations and their participation in the experiment, this process does not happen instantaneously. Oftentimes, further detailed discussion is needed. Frequently students need to re-run the experiment themselves in different roles (i.e. as launcher and catcher) and discuss what they are noticing before they trust their observations.

For this experiment to benefit the learning outcomes of the course and go beyond an understanding of a marble on a rotating table and the ocean and atmosphere dynamics at play, knowledge needs to be integrated into previous knowledge structures and transferred to other situations. This could happen by discussion of questions such as: How could the experiment be modified where a straight trajectory is observed on the screen? What would we expect to observe if we added a round tank filled with water and paper bits floating on it to the table and started rotating it? How are our observations of these systems relevant and transferable to the real world? What are the boundaries of the experiment?

**IS IT WORTH THE EXTRA EFFORT? DISCUSSION**

We taught an undergraduate laboratory course which included this experiment for several years. In the first year, we realized that the conventional approach was not effective. In the second year, we tried different instructional approaches and settled on the one presented here. We administered identical handouts before and after the experiment. These handouts were developed as instructional materials to ensure that every student went through the elicit-confront-resolve process. Answers on the handouts showed that all our students did expect to see a deflection despite observing from an inert frame of reference: students were instructed to consider both a stationary table and a table rotating at two different rates. They were then asked to, for each of the scenarios, mark with an X the location where they thought the marble would contact the floor after dropping off the table’s surface. Before instruction, all students predicted that the marble would hit the floor in different spots—diametrically across from the launch point for no rotation, and at increasing distances from that first point with increasing rotation rates of the table (Figure 4). This is the exact misconception we aimed to elicit with this question: students were applying correct knowledge (“in the Northern Hemisphere a moving body will be deflected to the right”) to situations that were not applicable: when observing the rotating body and the moving object upon it from an inert frame of reference.
In a second question, students were asked to imagine the marble leaving a dye mark on the table as it rolls across it, and to draw these traces left on the table. In this question, students were required to infer that this would be analogous to regarding the motion of the marble as observed from the co-rotating frame of reference. Drawing this trajectory correctly before the experiment is run does not imply a correct conceptual understanding, since the transfer between rotating and non-rotating frames of reference is not happening yet—and students draw curved trajectories for all cases. However, after the experiment, this question is useful especially in combination with the first one, as it requires a different answer than the first, and an answer that students learn they should not default to.

The students’ laboratory reports supply additional support of the usefulness of this new approach. These reports are submitted a week after completing the experiment and handouts. One of the prompts in the lab report explicitly addresses observing the motion from an inert frame of reference as well as the influence of the table’s rotational period on such motion. This question was answered correctly by all students. This is remarkable for three reasons: firstly, because in the previous year with conventional instruction, this question was answered incorrectly by the vast majority of students; secondly, from our experience, lab reports have a tendency to be eerily similar year after year which did not hold true for this specific question; and lastly, because for this cohort, it is one of very few questions that all students answered correctly in their lab reports, which included seven experiments in addition to the Coriolis experiment. These observations lead us to believe that students do harbor the misconception we suspected, and that the modified instructional approach has supported conceptual change.

CONCLUSIONS
We present modifications to a “very simple” experiment and suggest running it before subjecting students to more advanced experiments that illustrate concepts like Taylor columns or weather systems. These more complex processes and experiments cannot be fully understood without first understanding the Coriolis force acting on the arguably simplest bodies. Supplying correct answers to standard questions alone (e.g. “deflection to the right on the northern hemisphere”), is not sufficient proof of understanding.

In the suggested instructional strategy, students are required to explicitly state their expectations about what the outcome of an experiment will be, even though their presuppositions are likely to be wrong. The verbalizing of their assumptions aids in making them aware of what they implicitly hold to be true. This is a prerequisite for further discussion and enables confrontation and resolution of potential misconceptions. We suggest using an elicit-confront-resolve approach even when the demonstration is not run on an actual rotating table but conducted instead using, for example, Urbano and Houghton (2006)’s Coriolis force simulation. We claim that the approach is nevertheless beneficial to increasing conceptual understanding.

We would like to point out that gaining insight from any seemingly simple experiment, such as the one discussed in this article, might not be nearly as straightforward or obvious for the students as anticipated by the instructor. Using an intriguing phenomenon to investigate experimentally, and slightly changing conditions to understand the influence on results, is highly beneficial. Probing for conceptual understanding in new contexts, rather than the ability to formulate a correct answer, proved critical in understanding where the difficulties stemmed from, including detailed discussions with the students.

ACKNOWLEDGEMENTS
The authors are grateful for the students’ consent to be featured in this article’s figures.

RESOURCES
Movies of the experiment can be seen here:
- Rotating case: https://vimeo.com/59891323
- Non-rotating case: https://vimeo.com/59891020
- Using an old disk player and a ruler in absence of a co-rotating camera: https://vimeo.com/104169112

REFERENCES


ENDNOTES

¹ While tremendously helpful in visualizing an otherwise abstract phenomenon, using a common rotating table introduces difficulties when comparing the observed motion to the motion on Earth. This is, among other factors, due to the table’s flat surface (Durran and Domonkos 1996), the alignment of the (also fictitious) centrifugal force with the direction of movement of the marble (Persson 2010), and the fact that a component of axial rotation is introduced to the moving object when launched. Hence, the Coriolis force is not isolated. Regardless of the drawbacks associated with the use of a (flat) rotating table to illustrate the Coriolis effect, we see value in using it to make the concept of fictitious forces more intuitive, and it is widely used to this effect.

³ Despite their popularity in geophysical fluid dynamics instruction at many institutions, rotating tables might not be readily available everywhere. Good instructions for building a rotating table can, for example, be found on the “weather in a tank” website, where there is also the contact information to a supplier given: http://paoc.mit.edu/labguide/apparatus.html. A less expensive setup can be created from old disk players or even Lazy Susans, or found on playgrounds in form of merry-go-rounds. In many cases, setting the exact rotation rate is not as important as having a qualitative difference between “slow” and “fast” rotation, which is very easy to realize. In cases where a co-rotating camera is not available, by dipping the marble in either dye or chalk dust (or by simply running a pen in a straight line across the rotating surface), the trajectory in the rotating system can be visualized. The instructional approach described in this manuscript is easily adapted to such a setup.

³ We initially considered starting the lab session by throwing the marble diametrically across the rotating table. Students would then see on-screen the curved trajectory of a marble, which had never made physical contact with the table rotating beneath it, and which was clearly moving in a straight line from thrower to catcher, leading to the realization that it is the frame of reference that is to blame for the marble’s curved trajectory. However, the speed of a flying marble makes it very difficult to observe its curved path on the screen in real-time. Replaying the footage in slow motion helps in this regard. Yet, replacing direct observation with recording and playback seemingly hampers acceptance of the occurrence as “real”. We therefore decided to only use this method to further illustrate the concept, not as a first step.

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Researchers announced this past January that regular seafood eaters could be ingesting up to 11,000 microplastic particles per year. Although 99% of the particles pass through the body, at least one percent or about 60 particles, are absorbed into the body and do accumulate over time. In the ocean, plastic acts like a sponge picking up toxins and chemicals. Annually, about 8.8 million tons of plastic are dumped into the ocean, and about 9 million tons of plastic make its way into the world’s oceans. These plastics come from a diverse range of sources, including clothing made from synthetic materials. When these types of clothes are washed, they shed thousands of tiny plastic microfibers. These microplastics are then ingested by marine organisms which we, in turn, eat. In addition, the sun’s ultraviolet rays break down the plastic polymers into chemicals that disrupt human hormonal systems, especially those of adolescents and pregnant women.

Increasing evidence shows the negative impact of these plastics on marine organisms and humans. One such chemical component of plastics, described by Physicians for Social Responsibility, is Bisphenol-A (BPA). BPA is used in polycarbonate (i.e. hard) plastic products like water bottles, medical equipment, toys, consumer electronics, household appliances, and automobiles. Epoxy resins containing BPA are used as liners for many food and beverage cans and, surprisingly, in the very-common thermal cash register receipts.

We are pleased to report that a new collaborative effort between the National Association of Biology Teachers (NABT) biology club high school students in Los Angeles, California, Wakasa High School marine science students in Japan, and other student and environmental groups in Cambodia, Singapore, Chile, in addition to students in several other US states, are working together to form an international partnership to research the impacts of plastics. This school-to-school collaboration with Japan began in January of 2017 and already has students in each country selecting particular waterways, including harbors, oceans, and beaches to investigate types and the quantity of microplastics at these locations.

Japanese marine biology teacher, Yasuyuki Kosaka initiated this collaboration with the Animo High School Marine Biology Club in Los Angeles, California. In advancing this international collaboration, Kosaka presented the students’ research data from Wakasa High School at several workshops at the 2017 National Science Teachers Association (NSTA) convention in Los Angeles. He shared that the Japanese students found microplastic particles in the stomachs of oysters found in the Sea of Japan—a source of seafood (aquaculture and shell-fishing) for the city of Kyoto.

The NABT Los Angeles Microplastics Team from Animo High School had also collected water and sand samples from local sources such as Alamitos Bay, San Pedro harbor, and beaches at Dockweiler, Cabrillo, and Redondo and found tens of thousands of plastic nodules, macro and micro plastic debris, and substantial amounts of microplastics and filaments.

With instruction and collaboration with Linda Chilton (USC Sea Grant and NMEA board member), the Animo High School students developed standardized protocols. They took random quadrat samplings (with GPS coordinates) to a depth of 2 cm. Sand along with other biotic and abiotic matter was placed in buckets of water, the floating plastic was siphoned off and passed thru filter paper, and then counted.
For analyzing plastic in harbors and waterways, the Animo students used Algalita and 5Gyres protocols, focusing on plankton net tow for specific time and GPS coordinates, collection of biotic and abiotic matter from the cod-end that was poured thru filter paper and counted. This data was shared with other organizations and posted on a student developed website, featuring this club’s and other high schools’ research and action projects, articles, PowerPoints and videos, and plastic removal innovations.

The Microplastics Team captain Diana Cervantes from Animo High School shared that she had gained valuable experiences from the collaboration saying, “I have learned to be a better communicator and team player. Thanks to this overseas collaboration I’ve also learned how to communicate with different people, and how to properly get my messages across.”

Another member of the Micoplastics Team, Jessica Gonzalez had a similar experience. “We realized that there is little awareness in our community on plastic pollution,” Gonzales said. “We collected samples of microplastics at nearby beaches to show that microplastic pollution is a problem that directly affects marine organisms and humans. That initial passion to create awareness allowed us to present our research at science fairs to spark individuals from our community to make changes in their lives that will end the growth of microplastic pollution.”
Mikinori Matsui from Japan’s Wakasa High School says, “Through study of microplastics, I learned not only the seriousness of plastic pollution but also the importance of cooperation. We must collaborate with people in other countries to solve this global problem. Now we collaborate with Los Angeles students. Our research has become very exciting. We want to continue to find solutions to this problem with them.”

The high school students from Los Angeles were participants in the Algalita International POPS Youth Summit. Two Latina high school students from Los Angeles will be travelling to Chile in May, invited by NMEA member Carla Christie from the Universidad Austral de Chile, to present their findings and organize future collaboration with teachers and students.

All the NABT biology club high school members perform bi-lingual community outreach in Los Angeles. These take place at local aquaria (e.g. Cabrillo Marine Aquarium), parent meetings, health fairs, Earth Day, and other related events. One Saturday each month, the team leads LA Maritime Institute’s tall ship passengers on a hands-on research and data collection expedition in San Pedro’s harbor called, Explore the Coast/Explora la Costa, thanks to a grant from the California Coastal Commission. (The Commission supports environmental education programs that are often-overlooked in the Spanish speaking community.) The team teaches and shares the concerns about microplastics while passengers dissect Albatross boluses, separate plastic particulates from local sand samples, and discuss the human impacts and solutions during the expedition.

The high school students involved in the program around the world continue to share their research at local, regional, and international science fairs, while hoping to spread solutions to the microplastics problem as far as possible. For more information about collaborating on microplastic research and education at your local high school and access to the website and resources, see the author’s biography.

**Microplastics Team Solutions to Microplastics**

The team offers these solutions during presentations:

- Reduce food packaging
- Recycle existing plastic
- Adopt paper, bamboo, and cornstarch as a biodegradable substitute for plastic
- Make corporations pay for the clean-up costs of their businesses
- Advocate for more stringent environmental regulations while encouraging innovation and job creation

**REFERENCES**


Rathi, Akshat. (2017). Even your sea salt is contaminated with plastic. *Quartz Media, LLC*.


**MARK FRIEDMAN** is mentor to the Microplastics Team. Teachers and student environmental clubs interested in collaborating on Microplastic research and educational action campaigns can contact him at: Marklewisfriedman@gmail.com

...
SHARE YOUR IDEAS, LESSONS, or RESEARCH in Marine Education!

The editors of Current: The Journal of Marine Education are seeking articles for upcoming general issues. We hope to review and publish articles on topics related to marine education. We seek original manuscripts that describe research, lessons, resources, or strategies for teaching marine and aquatic lessons to a variety of audiences, including science, art, literature, and maritime history.

Please submit manuscripts to the editors at current@natl-marineed.org for consideration. The deadline for submitting articles for consideration in the Summer general issue is May 14, 2018.

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JOIN NMEA

We invite you to join us and share your ideas, resources, expertise, and inspiration with like-minded professionals.

Networking and building a sense of ‘family’ is a key benefit of our organization—however, members receive many other benefits as well: discounts at conferences, opportunities for scholarship and leadership, and many others. See http://www.marine-ed.org/?page=mbr_benefits for a complete list of benefits.

We have exciting initiatives happening both locally and globally and would love to collaborate with you!

You have many ways to get involved with this wonderful organization—join committees at http://www.marine-ed.org/ (click on Groups, then Committees), share your ideas, help with strategic initiatives, plan implementation, collaborate with other NMEA colleagues, and bring in new members (contact membership committee chair Lynn Whitley at lwhitley@usc.edu).

Go to the NMEA website at www.marine-ed.org and click on the “Join Us” link to choose your membership category and start the sign-up process.
January 2018

**Dear World of Water Lovers,**

As a member of the National Marine Educators Association (NMEA), you are an important part of the transformational and inspirational endeavors that our organization is working on, from championing Ocean Literacy across the nation and the world, to advancing educational practice in and out of the classroom, to mentoring the next generation of aquatic stewards.

NMEA provides to you, our members, a vibrant, engaging website, consistent e-newsletters, and a revived peer-reviewed journal *Current: The Journal of Marine Education*. Our national conferences inspire, educate and connect educators, researchers, scientists, students, and ocean stewards from around the globe. Our member elected Board, which you can be a part of, works with passion and dedication to guide the organization forward, as does the NMEA National Office.

**NMEA values members such as you, and we hope that you will further support the organization by joining us as we embark upon our fourth NMEA Annual Appeal.**

Financial support from our members helps us maintain our staffing in the National Office and provide the services necessary to run the organization with the consistency and efficiency you expect from a professional association. Your help is key as we implement our strategic plan and continue to strengthen NMEA to better “promote the world of water both fresh and salt.”

The exuberance for our organization, and the work it does, was evident during our lively and successful conference in Charleston, South Carolina this past summer. Your contributions to our collective knowledge and network are invaluable. What you contribute during an Annual Appeal also matters. Each and every gift provides a measure of the support needed to sustain NMEA as the global standard for aquatic/marine education.

You can make an unrestricted gift that will help underwrite daily operations, you can direct your gift to *Current*, or you can support a conference scholarship, including the Johnette Bosarge Memorial Fund. This fund, which honors the memory of our late Administrative Assistant, provides an annual conference scholarship to a member who best exemplifies Johnette’s selfless spirit and dedication to NMEA.

Thank you for being a member of NMEA, please consider a gift to the NMEA Annual Appeal.


Sincerely,

NMEA Board & Committees
NEW BOOKS AND MEDIA

Sea Stories

Author Dr. Danielle Dixson has developed a new children’s book series called Sea Stories, inspired by her own marine science research. Her first two books are titled, *A Butterfly's Journey to Find Delicious Food* and *How the Tiny Gobies Saved their Coral Reef Home*. With vivid illustrations and a story that young children will easily follow and enjoy, the books include topics on marine animals, ocean acidification, and the delicate balance between ocean inhabitants on a coral reef. For more information about the books as well as activities, visit Sea Story Books.

A Perfect Day for an Albatross

*A Perfect Day for an Albatross*, by Caren Loebel-Fried, an award-winning author and artist from Hawai'i, explores the world of albatrosses, and their intense commitment to one another and their nestlings. Set on Midway Atoll, where 72 percent of the world’s Laysan albatrosses make their nests, the story centers on Mālie, an albatross who must protect her egg until her mate returns. Educators can also download the Educational Guide that accompanies the book for access to activities that target national education standards for grades 1-3 at [www.birdsleuth.org/PerfectDay](http://www.birdsleuth.org/PerfectDay)—and for more information about the book, click here.

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Raise Your Paddles!

For the past two annual conferences, this has been the new call to action in fundraising for NMEA scholarships. During the boisterous, and ever popular, live auction, the auctioneer will shout out “time to raise your paddles in support of our scholarship fund!” What has ensued these past two years is an eager wave of paddles and bids; no bid is too small or too big. Last year, the paddle raise brought in a whopping $4,908! This is enough to support up to nine or ten full registrations to the annual conference. This is no small achievement and our generous members should be lauded for their contributions and exuberance.

It’s hard not to get caught up in the moment, and eagerly raise your paddle (or the paddle of a colleague) when the call to action is announced. I encourage everyone to consider how they can contribute, even if only a few dollars. Your dollars combined with a few others can easily add up and become a significant contribution. Joining forces is just one strategy for participation. You can also do a matching bid by announcing that you will match the next bid of $X, challenging your peers to join the fun. Of course, you can glow in the moment of raising your own paddle to bid your support for scholarships.

Scholarships are an important resource for NMEA membership. It provides access and opportunity for emerging (new) members to enter into our community through a conference or event. It enables participants from far away (international) to reduce the expense of attending an annual conference. And, it can provide support funds for members to attend chapter conferences and other meaningful NMEA-focused events around the country.

Thank you for your past contributions. Scholarship recipients, past and future, thank you as well. As you plan your session submissions and travel to the 2018 annual conference in Long Beach, CA, be sure to think about your strategy for the paddle raise. No matter how you contribute, we strongly encourage you to participate.

Cheers,

NMEA Board
All sessions, meetings, and workshops for this year’s annual conference will be hosted onboard the iconic Queen Mary.

We’ll be exploring people’s connections to the ocean, and how our work can move learners to productive action.

The Queen Mary is located just minutes from downtown Long Beach’s world-class restaurants and five uninterrupted miles of sandy beach. We look forward to seeing you in Long Beach!
INSIDE current
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Take the Plunge: A STEM Camp Centered on Seafloor Science

Meet the Grays

Engaging High School Students and Teachers Through an Ocean-Observing Technology STEM Outreach Club

Film Series Spawns Teen Ocean Stewards

Supporting Conceptual Understanding of the Coriolis Force Through Laboratory Experiments

If You Eat Seafood, You’re Probably Eating Plastic

NMEA Annual Appeal

New Books and Media

Raise Your Paddles!

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