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

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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 web page and via a "media blast" by 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

FIGURE 1. Clockwise from top-left: 1.) Undergraduate intern Ben Carothers instructs custom sensor software code at a meeting in the SO-COOL educational space; 2.) Dr. Ryan Schloesser of the Mote Marine Laboratory Fisheries Ecology and Enhancement Program demonstrates fish tag detection technology; 3.) Members construct the platform for the custom sensor at Phillippi Creek; and 4.) Dr. Jordon Beckler demonstrates buoyancy concepts related to Mote's AUV glider, "Genie." Courtesy of Mote Marine Laboratory

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

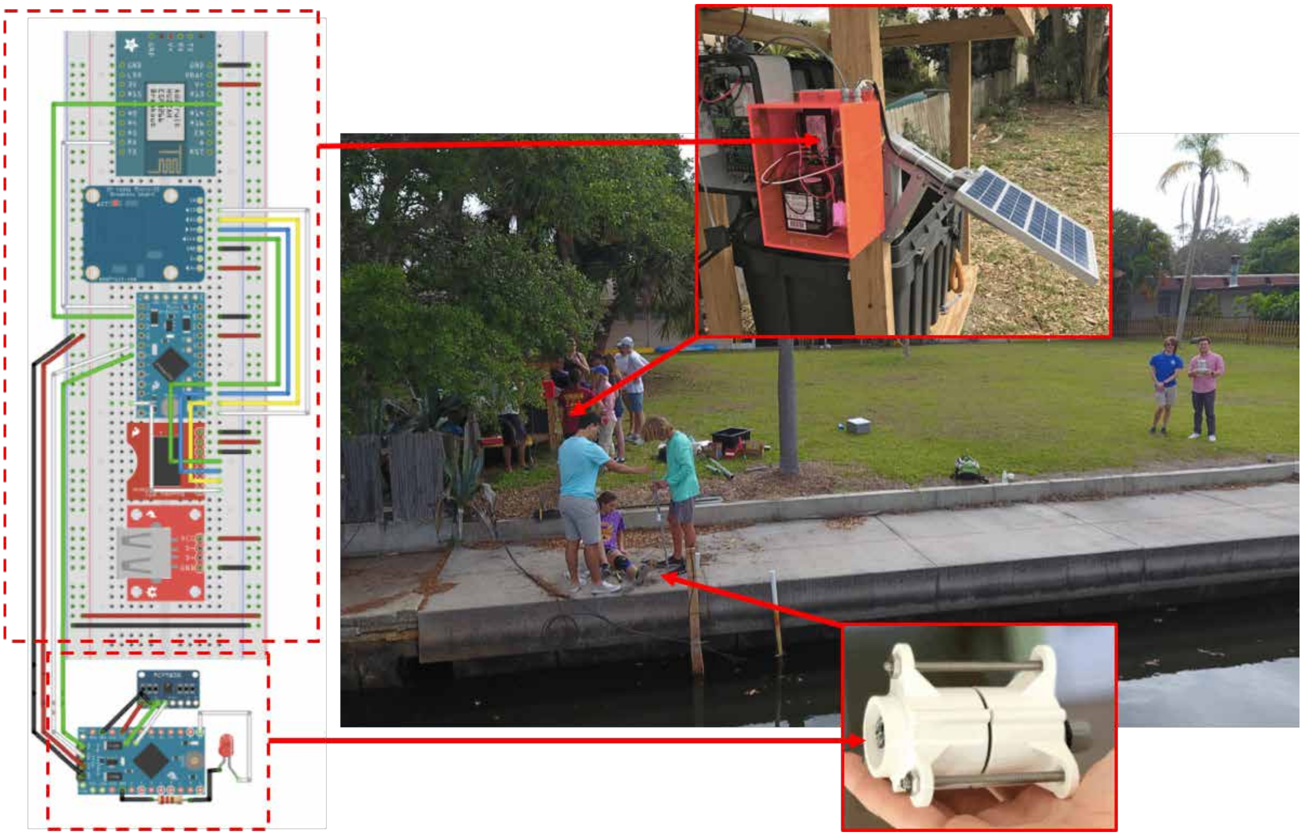

FIGURE 2. Unmanned Aerial Vehicle captured photograph of club members installing a sensor platform at Phillippi Creek site (PL2; drone operators in right hand side of frame). The upper sub-pane illustrates the electronics housing (laser cut from orange acrylic) containing the battery, solar charge controller, and electronics breadboard with hardware components (left; diagram created in Fritzing, see resources). The temperature sensor is wired to the main breadboard and housed in a waterproof PVC module (modeled after Cave Pearl Project, see resource section), which is affixed to a secure PVC pipe for long-term monitoring. Courtesy of Mote Marine Laboratory

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 association and browse the site to research:

1. What issues are most important in your IOOS regional association?
2. What types of observatories are in place to monitor these issues?
3. Do they use gliders? Do they have their own AUV glider "portal," similar to the GCOOS Gulf AUV Network and Data Archive Long-term storage Facility (GANDALF)?
4. How about acoustics and fisheries?
5. How about education and outreach? What types of activities?
6. Any information regarding their "build-out" plan? What is needed?

Finally, the teams were asked to present their findings to the larger club (four minutes/group). From an educator's perspective, this seemed to be one of the most exciting, fun, and interactive activities of the club.

Conduct red-tide monitoring: The Gulf coast of Florida is plagued by harmful algal blooms of Florida red tide (*Karenia brevis*), which cause tens to hundreds of millions of dollars annually in economic and health impacts (Vargo 2009). While most residents in the Sarasota-Manatee County region are familiar with red tide, Mote's efforts and instrumentation used to study and help mitigate the effects of blooms were detailed during the first and fifth club meetings. Additionally, club members were invited to participate in deployments of Mote's AUV glider "Genie," in which they enjoyed a fun and informative boat ride onboard one of Mote's research vessels, gained exposure to oceanographic logistics, and obtained samples using a "Niskin" bottle, one of the most standard tools of an oceanographer.

Explore the sensor data streams: The curriculum for the club was admittedly ambitious, and all four of the sensors did not function properly for installation in the field prior to the end of the club. However, data was obtained completely remotely and autonomously for a short period of time from the site that the students installed the sensor (site PL2), allowing for the data to be plotted and viewed in the final club session (Figure 3). The club members were impressed with their data stream and an active discussion ensued. They were surprised to see that at higher tides, the seawater was of a higher temperature than the land; and they also speculated about why the temperature measurements had a split peak when they were at their highest values. It was agreed that more effort was needed for analyses and that some members would pursue this work over the summer.

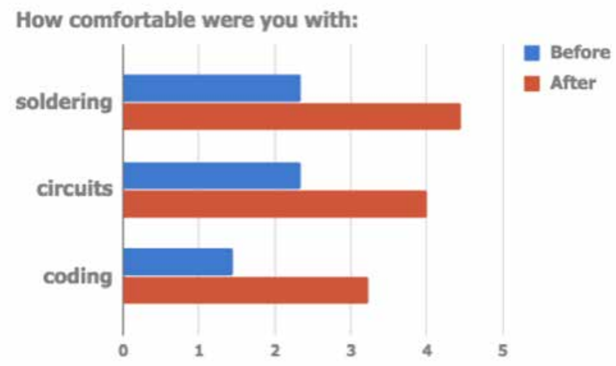

FIGURE 3. Temperature measurements of the bottom water at the Phillippi Creek site PL2 from the sensor installed by the club members, and depth measurements at a NOAA buoy in Naples for comparison. The temperature measurements are generally in sync with the tide measurements, and this time series plot 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,

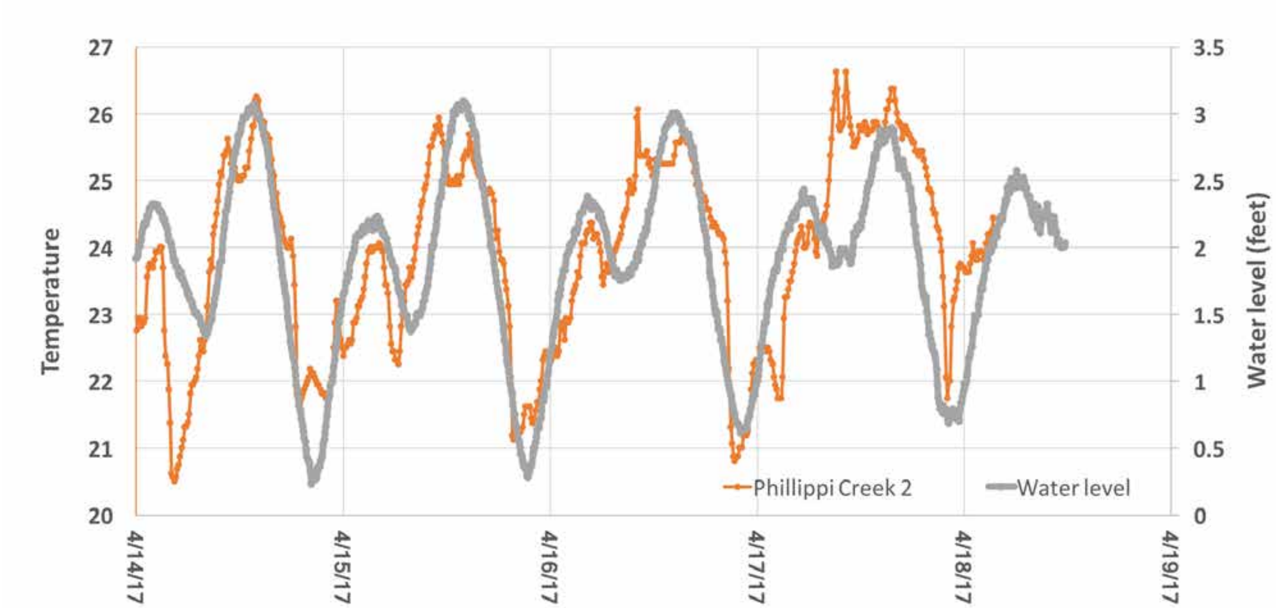

FIGURE 4. Club members were considerably more confident in their abilities to solder, construct electronic circuits, and code; however, it was agreed that more coding experience was necessary (averages, n=9). Courtesy of Mote Marine Laboratory

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 Instruements: http://www.loggerhead.com/opentag-motion-datalogger
- Suncoast Science Center: http://www.suncoastscience.org/
- Wevolver: https://www.wevolver.com/

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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

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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.