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Title: Establishing Interest In And Understanding Of The Marine Environment: An Educational And Cooperative Approach Utilizing An Open Source CTD

Abstract approved:

Flaxen D.L. Conway

A number of groups in the United States have expressed concern regarding the state of public ocean literacy and the capabilities of the future marine STEM workforce. This pilot study explores some of the requirements for workforce development and the expansion of ocean literacy by introduction of fundamental ocean properties through the application of an open source oceanographic instrument. Three core ocean properties - salinity, temperature, and depth - are collected by a device called a CTD and are prolifically utilized by all disciplines of oceanography, industry, and recreation. Using education and engagement methods similar to the MATE ROV program, eight students from a coastal high school in Oregon were tasked with constructing multiple open source CTDs and participated in a number of experiential learning activities. Student perspectives were captured using pre-assessment and post-assessment questionnaires, providing insight into their interest in STEM, ocean science, and related careers. The student-constructed devices were then delivered to local commercial fishermen for testing and data collection. Fishermen perspectives were captured using semi-structured interviews focusing on their interest in cooperative science and data use. Six months of observations and data collection suggest that a learning experience centered about an open source CTD does have some impact on student interest in STEM, ocean science, and related careers. The specific use of the device and resultant data does not have a significant influence on fishermen interest in participating in cooperative science, but that interest lies in other unanticipated factors. Proper integration of a marine technology into the learning environment may provide students with skills needed in today's marine workforce and may also provide them with a fundamental oceanographic background for enhanced ocean literacy. Continued cooperation may enhance fishermen understanding and valuation of the marine environment, but potentially in a different capacity from how it is currently understood. This thesis is concluded with some project limitations, suggestions, and several future project ideas that may prove to increase interest in the marine STEM workforce, provide vectors for improved ocean literacy, and lead to pathways for valuation of the marine environment for all.

Establishing Interest In And Understanding Of The Marine Environment:
An Educational And Cooperative Approach Utilizing An Open Source CTD

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Major Professor, representing Marine Resource Management

Dean of College of Earth, Ocean, and Atmospheric Sciences

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Ian Black, Author

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Stuart Pearce is credited for introducing me to the open source CTD concept and for coining the name *CTDizzle*. Delirious after a long mooring deployment, the name emerged late at night on July 1st, 2016 while performing a CTD cast from the R/V Ron Brown. At the time we thought it was hilarious and it became the official callsign for the CTD developed as part of this research. Unfortunately, Snoop Dogg did not reference the CTDizzle in his latest album.

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Introduction, Background, and Objectives

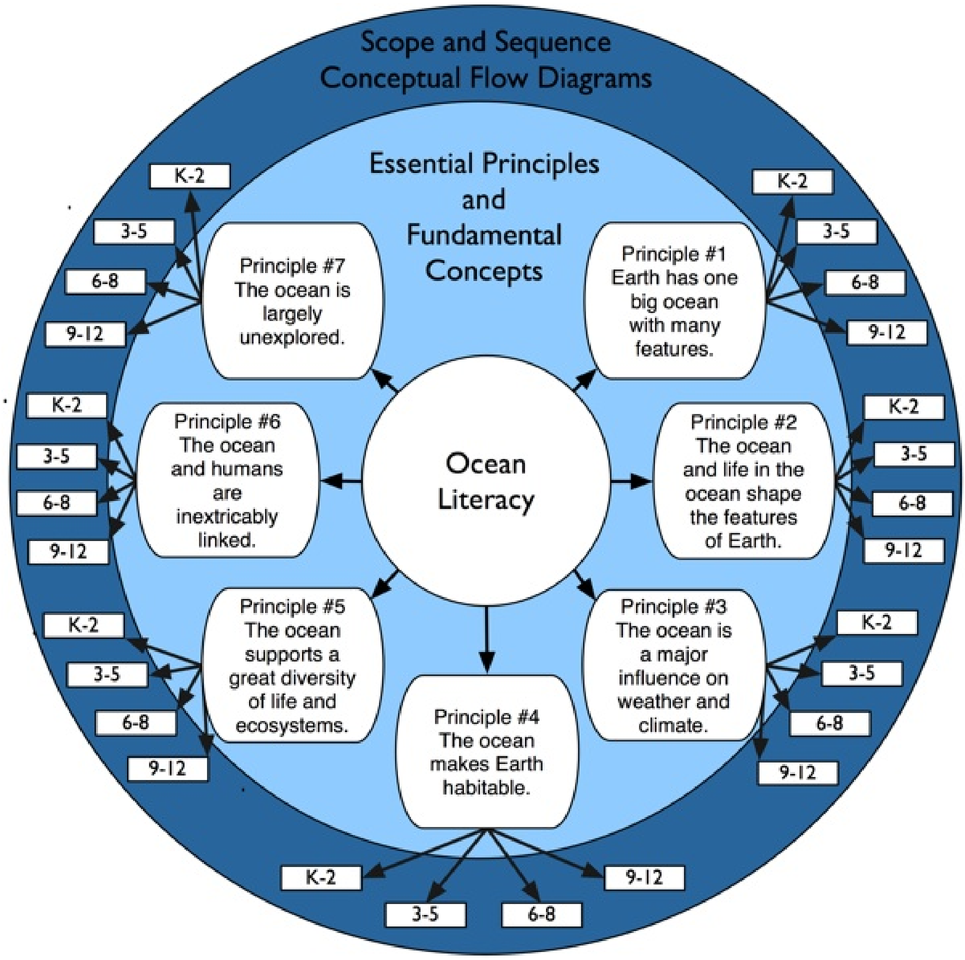
1.1 Technology, People, and Ocean Literacy

Since the dawn of humanity, technical ingenuity has allowed humans to make significant strides in navigating, studying, harnessing, and deciphering the sea. At the beginning of the 18th century, the invention of the sextant improved a marine navigator's ability to traverse the Earth's waters. Sonar readings from the 1970s allowed Marie Tharp and Bruce Heezen to develop and commission one of the most iconic global bathymetric charts still referenced in current literature. The continued development of autonomous underwater vehicles today has provided researchers with the ability to study a myriad of physical, biological, chemical, and geological parameters over large amounts of time and at great depth; all from the comfort of a sofa. Professional study of the ocean is still relatively young, but since the beginning of the Anthropocene we have observed that the ocean is a place that is diverse, deep, dark, damaging, and dynamic. Without the assistance of technology, we simply would not know as much about the marine environment as we do today.

From the tidally influenced Quebec City to the bottom of the Marianas Trench, the vast seascape is a shared space between many different species, processes, and people. With nearly 40% of the United States (US) population living within 40 miles of a coastline, many people rely on the ocean as source of capital, culture, recreation, and sustenance. Despite a significant portion of the population having some relation to the marine environment, there is an expressed need for improved public ocean literacy within the United States (Steel et al., 2005; Plankis and Marrero, 2010). This circumstance has also been observed in many other countries worldwide (Guest et al., 2015; Seys et al., 2008; Fletcher et al., 2009; Eddy, 2014; Kim, 2014; Leitao et al., 2018). Ocean literacy can be defined as having an understanding of how the ocean influences your life and how your life influences the ocean. One who is ocean literate also has the ability to understand certain principles and concepts from one or multiple ocean disciplines, communicate ocean topics in a purposeful manner, and is able to make informed decisions with regard to ocean services and resources (Ocean Literacy Initiative, 2005).

The Ocean Literacy Framework details seven core principles that are key to becoming more ocean literate (Figure 1.1) (Ocean Literacy Initiative, 2005). The principles tie in with the National Science Education Standards (NSES) and are intended for use in public education (Ocean Literacy Initiative, 2005). Each principle on the guiding diagram branches into concepts that should be understood by a particular grade level group, with emphasis on the science that underlies each principle, how best to approach development, and how each concept builds toward a higher-level understanding.

Figure 1.1: Ocean Literacy Framework: Essential Principles and Fundamental Concepts



Direct link to interactive diagram: http://oceanliteracy.wp2.coexploration.org/?page_id=756

Greater levels of ocean literacy can lead to a greater understanding of the importance of the ocean. Although geared toward understanding in the learning environment, these key principles are also transferable to the larger public. The public is made up of those that use and value the ocean in different capacities, such as students, educators, surfers, fishermen, seafood aficionados, yachters, and many more. One way to engage these groups and to make them more ocean literate is to provide readily accessible information. Another way is to establish new and exciting avenues for learning.

The ocean is a substantial source of life, activity, sustenance, and culture for many on Earth. As climates continue to change and the shared seascape becomes more congested, the need for environmental data will increase in response to the need for more sustainable and evidence-based management and decisions. This translates to a demand for individuals who are not only ocean literate, but who have the capacity to develop and understand how environmental monitoring technology works, who are willing to participate in shared research endeavors, and who play a role in policy and decision making. Through the efforts of these individuals we can develop new technologies that help us study the ocean, monitor larger swaths of water, and further anticipate the effects that humans have on the marine environment; thus allowing us to adapt accordingly in a sustainable fashion.

1.2 Schools, Marine STEM, and Experiential Learning

In the early 2000s, it was observed that ocean education was greatly underrepresented in primary and secondary (K-12) education within the United States. There appeared to be an overall lack of reference as to the importance of the ocean in texts, assessments, standards, and curriculum materials (Ocean Literacy Initiative, 2005; Cava et al., 2005). Initial drafts of the 2014 Next Generation Science Standards (NGSS) appeared to be terrestrially biased, with little inclusion of ocean specific topics (Strang, 2012). The NGSS now contains specific ocean examples in sections such as human sustainability, Earth and human activity, weather, and climate (NGSS Writing Team, 2014). This sets the stage for the development of ocean literate individuals over the next generation. Ocean literacy does not only consist of scientific knowledge, but also involves consideration of relationships between ocean users and the effect that humans have on the environment. This thesis focuses on marine education by primarily using science, technology, engineering, and mathematics (STEM) as a vehicle for ocean literacy.

A bibliometric analysis of the term *ocean literacy* reveals that there have been a little over 50 publications that have utilized the terminology since the early 2000s (Costa and Caldeira, 2018). Of these publications, some discuss methods for enhancing student ocean literacy in primary, secondary, and tertiary education through vectors such as books, radio, television, mobile computing, science center attendance, and experiential learning (Leitao et al., 2018; Schnetzer et al., 2016; Kim, 2014). Experiential activities such as Ocean Sampling Day place individuals in the field and engage them in the experience of data collection and analysis. Those that have participated in Ocean Sampling Day in the past have felt that they are more engaged with ocean issues after the event (Schnetzer et al., 2016). This, in addition to other hands-on projects like the building of a remote-operated vehicle and piloting of a drone, follows the suggestion from Guest et al. (2015) that experiential learning may be an effective method for improving student ocean literacy, in addition to enhancing valuation of the ocean and marine stewardship.

STEM activities involving hands-on and lab-based learning have always been a supplement to the standardized classroom environment, but are now becoming central in teaching both inside and outside of school. Many technology-based activities, such as the use of a 3D printer to create a physical object, have been successful in influencing student STEM literacy, interest in continuing STEM education, and the pursuance of STEM-based careers (Kostakis et al., 2015). This is important because the upcoming generation will contribute significantly to innovation and the future development of technology; both significant drivers for the US economy (Dedrick et al., 2003; Atkinson and Mayo, 2010). STEM programs are becoming more prominent in high schools today, offering students the opportunity to develop skills needed in the STEM workforce. Marine and technology-based STEM has also begun to shape how learning is accomplished.

Informal education entities, such as Oregon Sea Grant (OSG), have created STEM programs that utilize the coast as a classroom, providing coastal students the opportunity to learn in a more localized setting, to make connections between the ocean and human activities, and to learn more about marine-related careers. The marine environment influences many lives, and as such it is important to incorporate it into the classroom setting and learning activities. Promotion of the ocean to the next generation is key for future development and involvement. Today's students will be tomorrow's fishermen, surfers, oceanographers, marine technicians, military, policy-makers, and managers; all which share and play a vital role in the status of the ocean and how we utilize it.

1.2.1 Influence of Marine Technology Centered Activities

The Marine Advanced Technology Education (MATE) Remote Operated Vehicle (ROV) competition is one experiential learning platform that engages K-12, community college, and university students in both technology and the marine environment. There has been an observed deficit in scientific, technological, and operational personnel in marine-based fields (Zande, 2011). The mission of the MATE Center is to utilize underwater ROVs to teach STEM to students, equip them with skills commonly found in technical careers, and prepare them for the marine workforce. Students are required to build a ROV, pilot it in a pool, and complete a predefined mission. Missions vary in difficultly based on group age, but in the past have had tasks such as the placement of sensors at a hydrothermal vent to monitor the temperature and content of crustal water. This year (2018) the context of the mission was for students to be able to create an ROV that could locate and recover a portion of an airplane wreckage, install a seismometer, and set up a tidal turbine.

Students are introduced to more than just the mechanical workings of underwater robots. They learn about different career paths from vendors, industry, and user groups present at the competition, as well as how ROVs are applied in the real world and how the data they collect in-situ can be utilized for efforts such as spatial mapping and species analysis (Levin et al., 2007). From a technical perspective, students must learn the basics of buoyancy and ballasting of the ROV, thruster control, and how to mitigate leaks and electrical shorts to create an operational unit. The list of topics is wide and depends on the complexity of the ROV and what an instructor feels is necessary for the students to learn. Additionally, students must present their ROV build to a group of professionals and effectively communicate reasoning for the design, draft a manual detailing the technical aspects, and create a poster about their experience.

Compiled from 2008-2010 international competition data, it has been found that participation in the competition, the experience of building the ROV, and the presentation of work has had a positive influence on student awareness and interest in marine-related careers and STEM education (Mann, 2011). Student data consisted of 1,025 (N_{total}) surveys completed by a mix of elementary, middle, and high school, as well as community college and university level teams. For each year, more than half of the participating schools were high schools. From this study, 97% (N=996) of students agreed that the MATE ROV program had made them more aware of careers in marine science and technology. 74% (N=997) stated that the experience also made them more interested in pursuing a marine-related career. From the 2010 MATE ROV international competition, 83% (N=325) of students believed that this project made them more interested in ocean science, technology, and engineering. The majority of students also indicated an increased interest in taking more courses in science (62%), engineering (74%), shop (79%), and computer science (51%), while there was a lack of majority interest in mathematics (45%). From all years, one third of participating students (N=984) felt that their participation in the ROV competition offered pathways to new educational or career opportunities (Mann, 2011).

The skills described in the Secretary's Commission on Achieving Necessary Skills (SCANS) report are skills determined by the US Secretary of Labor that prepare young individuals for success in the US workforce (SCANS, 1991). While SCANS skills consist of general items such as reading, writing, problem solving, and sociability; in the context of MATE it also involves being able to select, apply, maintain, and troubleshoot technology and equipment. 98% (n=65) of teachers and mentors who participated in the study also observed improvements not only in their students' STEM skills, but also in their team building, problem solving, and critical thinking attributes as a result of participating in the competition experience (Mann, 2011).

The use of aerial drones to teach marine science concepts is another example of a technology centered activity that has the potential to influence student interest in marine science. The Coastal Drone Academy teaches students how to pilot drones and utilize them for scientific applications. In its third year, students have used drones to monitor wetland restoration processes, map seagrass extent, and collect whale snot (Getter and Keene, 2017). Through a curriculum accepted by the Federal Aviation Administration (FAA) students are actively engaged in coastal research and learn about resource management and issues. Students that complete the program and obtain enough flight hours are also given the tools necessary to obtain the FAA Remote Pilot Certificate and pursue other certifications. Although in its infancy, educators can utilize this curriculum to teach a variety of marine STEM topics and provide students with workforce transferable skills.

1.3 Cooperative Research and Ocean Users

Cooperative research provides an opportunity for marine researchers and other ocean users to develop partnerships and gain an understanding of another perspective. Ocean-going researchers and scientists have utilized the assistance of ocean stakeholders to perform studies and experiments for many years. Not only do these individuals or groups provide physical assistance in the form of vessels and gear deployment, but their observations and local ecological knowledge (LEK) are incredibly valuable (Anadon et al., 2009; Cigliano et al., 2015). Often these other users have a vested interest in learning more about the ocean, developing relationships with scientists, and becoming a stakeholder in management and policy decisions. The information these partnerships collect holds value for both groups and can increase the precision, resolution, and length at which we can perform environmental monitoring (Manning and Pelletier, 2009). Unable to monitor the ocean all the time, more researchers are looking to other users in cooperative, collaborative, and crowd-sourced efforts.

Public and stakeholder motivation for participating in research projects and taking on the role of citizen scientist can vary by group and individual. Motivations for participation in environmental monitoring projects can include, but are not limited to, enjoyment, enthusiasm for the goals of the project, contribution to a particular endeavor, connection to the natural world, and conservation (Roy et al., 2012). Motivation of the participants can also be normative and stealth policy driven, as some could believe that their collected data could be utilized as a means to end. On the opposite side, participants could also object to collecting data if they feel that it could be utilized for policy decisions that could be detrimental to the shared use of the marine environment (Grove-White et al., 2007). A significant hurdle in developing a project involving citizen scientists is providing a data product that is optimal for all groups involved. Attempting this can sometimes be nocuous as the project may become unappealing to a particular group or place a significant demand on a participant (Roy et al., 2012).

1.3.1 Working With Fishermen

Commercial fishermen are not strangers to science nor are they unfamiliar with researchers. Research involving the partnership of fishermen commonly consists of gear studies, stock-assessment research, or ecological research (McCay et al., 2006; Vestfals, 2009). From the viewpoint of the fishermen there can sometimes be a negative stigma associated with scientists. The science is often viewed as acceptable and there is little doubt that data is inaccurate, but it is scientists who utilize it in a normative fashion and for stealth policy advocacy that bring about the negative stigma (Lackey, 2016). A hurdle for the development of positive relationships lies in communication, trust, and respect (Kaplan and McCay, 2004; Conway, 2006). Lack of trust can prove to be deleterious to the working relationship between fishermen and scientists when the information fishermen provide holds value and has the possibility of inciting economic competition or negative management development(Childress, 2010; Bergmann et al., 2004). Opposite to that, there are fishermen that participate in cooperative research that greatly value the relationships that are generated or improved through interaction (McCay et al., 2006).

The LEK of fishermen is incredibly valuable to the scientific community and is being utilized more frequently in studies. Fishermen are always talking about fish, how they behave, and how they interact with other species and the physical environment. From the viewpoint of the scientist or researcher, this information is sometimes thought of as anecdotal and of lesser value, but contrarily it has been found to complement conventional data collection methods (Silvano and Valbo-Jorgensen, 2008). Information that fishermen provide could assist in improving the management of a fishery or point toward areas of interest for researchers (Johannes, 1981; Berkes et al., 2000). Although biological and ecological studies are engaging, fishermen appear to prefer gear studies over other forms (McCay et al., 2006). Coincidentally, the technical and operational knowledge of fishermen is more often utilized and valued by scientists. Fishermen have held and will likely continue to hold key roles in studies involving fisheries and environmental research in the future.

Cooperative research with fishermen is the first step toward developing effective collaborative research, where fishermen take on a shared leadership role in how scientific research is approached, executed, and managed (Conway and Pomeroy, 2006). There are a multitude of advantages found within the collaboration between fishermen and scientists, but difficulties can be more prominent if either group perceives a differential in the shared workload or if other conflicts arise related to perceived benefits (Yochum et al., 2011). Data ownership also plays a large role in how fishermen perceive a project. Having control over the data and how it is used is one reason fishermen may be more willing to participate in a research project (Kumar, 2017). In a world afflicted with climate change, anthropogenic and natural disasters, and a growing population, increasing the number of opportunities to collect environmental data creates more opportunities to learn and make strategic decisions in policy, management, and everyday life.

1.3.2 Scientific Research and Platforms of Opportunity

In 2009, fishermen based out of Newport, Oregon were part of a study that utilized crabbing gear to deploy dissolved oxygen sensors to the benthic environment. The purpose of this study was to determine if crab pots would be suitable research platforms of opportunity, with assistance from the perspectives of fishermen and researchers, to expand ocean monitoring efforts along the Oregon coast (Childress, 2010). Fishermen involved with this project were part of a group called the Oregon Fishermen In Ocean Observing Research (OrFIOOR), with the majority of them having an inherent interest in science and the improvement of ocean monitoring efforts. Findings from this research showed that the fishermen involved wanted to continue collecting data and were willing to allow use of their time and vessels as environmental monitoring platforms. However, there was a perception among participants that peers not familiar with researcher interaction may be cautious with scientists and more focused on economic value, thus unwilling to participate in cooperative research. There was also an interest in observing possible correlation between dissolved oxygen concentration, temperature, and catch size, but the confidentiality of the metadata was a primary concern among the OrFIOOR participants. Overall, both the majority of researchers and fishermen involved felt that crab pots were acceptable platforms of opportunity but efforts were needed to successfully incorporate that information into archive and distribution platforms that could be utilized by both groups (Childress, 2010).

1.3.3 Information Centered Cooperation

The combination of information and communication technologies (ICTs), fishing vessels as platforms of opportunity, and fishermen LEK is the basis of Abalobi, an application suite for South Africans that promotes social justice and poverty alleviation of small-scale fishers, fishery sustainability, and resiliency in a changing world (Kumar, 2017). The Abalobi Initiative is a participatory program with fishermen taking the lead role of data collection. The end goal of the project is to create an information management system that can be used to aid in the creation of policy and management formats that are beneficial to small-scale fishers. The app allows fishermen to input catch data on their mobile devices and share that information if desired, allowing for use of that data in evidence-based decision making and policy development (Kumar, 2017). The application also allows fishermen to access real-time fishery information and oceanographic data relevant to their needs, as well as post observations from daily activities. The system is open source in nature, and some aspects are still under construction, but it has received all around positive reviews from users (Abalobi, 2018). Participants are not opposed to the use of technology and cooperative research; however, the primary motivation for participation appears to be from a stewardship perspective rather than a monetary one.

Seacast.org, currently being integrated into the Northwest Association of Networked Ocean Observing Systems (NANOOS), is a website that provides three-day forecast information for wind, wave height and direction, currents, temperature, salinity, and sea surface height through a convenient and simple user interface. It was built through cooperation between Oregon coast commercial fishermen and Oregon State University researchers and is another example of information-centered cooperative research resultant from capability and need for centralized data products (Duncan, 2014). The website was designed explicitly for use by Oregon coastal fishermen and provides information in a format that is easily discernible by users. Fishermen are pragmatic in their thinking and in turn displayed data must follow a practical format that assists in decision making. However, from some users there is concern regarding the accuracy of the forecast and modelers are finding it difficult to communicate a response. The accuracy of data and models plays a distinct role in how fishermen utilize and understand information. The decisions they make are often based around risk, safety, and economic gain (Kuonen, 2018).

1.4 Oceanography 101

1.4.1 Platforms and Sensors of Operational Oceanography

Apart from the people that keep ocean observing systems maintained, accessible, and funded; our capacity to observe the marine environment largely depends on the capability and availability of in-situ sensors, observational platforms, and satellites. The ocean is pocketed with environment monitoring systems above and below the surface, ranging in size from the diameter of a quarter (2.5cm) to the average depth of the ocean (4km). Common in-situ platforms include autonomous underwater vehicles (i.e. gliders), ROVs, research vessels, surface moorings, subsurface moorings, profilers, benthic experiment packages, and floats. These platforms measure a variety of parameters such as salinity, temperature, dissolved oxygen, wind speed and direction, photosynthetically active radiation, pH, pCO2, and fish biomass. The National Science Foundation's Ocean Observatories Initiative (OOI) is the largest civilian ocean monitoring effort currently in existence and produces more than 200 data products from 75 instrument types in near real-time from two coastal, two global, and one cabled node. Small-scale projects, such as the Newport Hydrographic (NH) Line and the Tropical Atmosphere Ocean (TAO) Array, provide more specific data products for a particular region where phenomena can have regional or global impacts. If there is a desired data type, there is likely an instrument and platform that can measure it. Operational oceanography provides researchers with the means to make connections between spatial and temporal segments of the natural world. Scientists are able to study large circumstances such as coastal ocean dynamics and ocean-atmosphere exchange, as well as small-scale occurrences involving biophysical interactions in an estuary or localized eddy circulation.

1.4.2 Cost of Science

Operational oceanography is expensive, largely due to the caustic nature of the ocean, the vast area it covers, and the time frame at which oceanographers wish to collect data. Regional and global class research vessels can cost on the order of tens of thousands of US dollars per day to operate. Mesoscale moorings outfitted with a multitude of subsurface and atmospheric sensors can cost the American taxpayers millions of dollars to maintain. Electronics and water also tend to not mix well. In-situ instrumentation designed for depth is typically made out of hearty materials that mitigate the possibility of water intrusion and implosion, such as titanium or acetal homopolymer. Many instruments also utilize complex processes to derive data products and require the use of a reliable user interface to allow for data collection and analysis, further adding to the cost. The effects of biofouling and galvanic corrosion also result in a high instrument turnover rate, requiring that instruments be cleaned and refurbished periodically. Sustained observations today rely largely on affordable platforms and methods of data collection, rather than technical advancement (Griffiths et al., 2001). Researchers are sometimes unable to obtain data at the scales they desire given the high cost associated with design and implementation of environmental monitoring programs.

The cost of marine sensors, with the exception of devices such as the Secchi Disk, can be significant and a restrictive factor for sustained in-situ observation projects, especially for early-career scientists, low-funded projects, educators, students, and citizen scientists (Griffiths et al., 2001). High cost can also be a prohibitive factor for managers interested in environmental monitoring as well as those looking to optimize spatial resolution of research efforts (Pinardi and Coppini, 2010; Lockridge et al., 2016; Hund et al., 2016). Recent developments in low cost sensors and open source microcontrollers have made it possible for these groups to develop, construct, and test instruments for use in operational oceanography. While often not as accurate, precise, or robust as commercially produced variants, the nature of these open source devices allows users to collect useful oceanographic data at a variety of scales and at a lower price point per unit.

1.4.3 Conductivity, Temperature, Depth

The CTD is the workhorse tool of oceanography (Thaler et al., 2018). It is one of the most common oceanographic sensors in existence and the information it collects links all disciplines of oceanography. CTDs can be found on almost every monitoring platform in the ocean, as many other instruments utilize and rely on the information it collects. Electrical conductivity (C), temperature (T), and absolute pressure ("D", i.e. depth) are combined in a series of computational algorithms that output information such as salinity, density anomaly, and the speed of sound in seawater (Fofonoff and Millard, 1983). Essentially, the CTD provides oceanographers with information about the basic physical properties of the Earth's oceans. Salinity and temperature can be used to make inference to how the global ocean moves over long time scales and how the water column structure of an estuary changes with tides and freshwater input. Salinity and temperature also impact other biological, chemical, and geological parameters, as well as how we measure them. For example, the accuracy of a dissolved oxygen measurement partially relies on the accuracy of the measured temperature and salinity, as solubility of the gas is impacted by both factors (Garcia and Gordon, 1992). In a typical introduction to oceanography course, the CTD, salinity, and temperature are some of the first topics introduced.

CTDs come in a variety of shapes, sizes, and different manufactured versions require different levels of technological skill in order to operate. The most prominent CTD manufacturer is Seabird Scientific (previously Seabird Electronics). Seabird has set the standard for CTD quality, with most of their instruments boasting 16Hz sampling rates, temperature accuracy to the nearest 0.005 °C, conductivity accuracy to the nearest 5 $\frac{mS}{cm}$, and sub-centimeter depth accuracy (Sea-Bird Scientific, 2017). Seabird makes CTDs for profiling applications on profilers, research vessels, and gliders, as well as for time-series applications on moorings, drifters, and bottom packages. Seabird has developed algorithms for their CTDs that factor in problems such as shed wake, the effect of water flow on temperature, conductivity cell compression, and the time lag between conductivity and temperature readings. Young Springs Instruments (YSI) is another group that makes the Castaway CTD, a profiling CTD utilized by many government agencies and research projects today. The Castaway has a much smaller form factor compared to other manufacturers and relies on gravity to take measurements throughout the water column. It is unique in that it has the ability to communicate with a computer via a provided Bluetooth adapter, allowing users to wirelessly transfer data without opening the pressure case.

CTDs, like most instruments designed to collect data at depth, are expensive. Commercially produced variants can cost on the order of thousands to tens of thousands of US dollars depending on the application. On the other hand, a user-built open source CTD can cost several hundred to several thousand dollars, but lacks the software, technical, and informational support that commercial manufacturers provide. Although they may not be as accurate and require substantial fine-tuning, open source CTDs can be an alternative to commercial variants in some studies, where multiple CTDs are needed for high resolution measurements or to cover a large area (Lockridge et al., 2016). Table 1.1 shows a comparison between the approximate costs of two common commercial CTDs and two known Arduino-based open source CTDs. Further descriptions of the open source variants appear in Section 1.5.

Table 1.1: CTD Price Comparison

Name	Group	Cost (USD)	Application
16Plus	Seabird Scientific	10,000	Stationary/Profile
Castaway	YSI/SonTek	6,400	Profile
OpenCTD	Oceanography For Everyone	350	Stationary/Profile
Arduino Sonde	Lockridge et al.	300	Stationary/Drifting

Cost is approximated from quotes given in person and emails from vendors.

1.5 Open Source Sensors

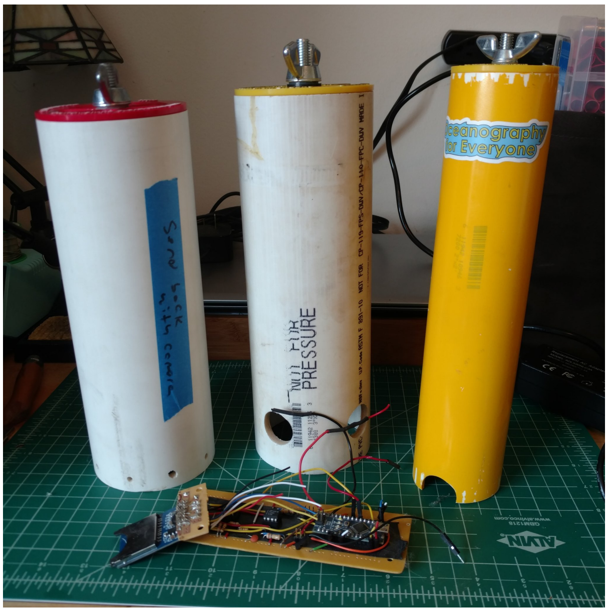
The open source concept has been around for several decades and is a core component of the CTD developed as part of this research. Microcontroller platforms, such as Arduino and Raspberry Pi are governed by open source software, essentially allowing a user to obtain, modify, and redistribute the source code without significant fear of copyright infringement. Many companies that develop microcontroller-compatible sensors are now applying the open source concept to their designs and are making diagrams and schematics freely available for users to modify. Several groups and individuals have developed open source variants of a CTD, largely based around Arduino-compatible boards and the Raspberry Pi (Thaler and Sturdivant, 2013; Lockridge et al., 2016; Haan, 2017). By enabling a non-discriminatory and non-restrictive license, others can build off of and continue to improve designs.

1.5.1 The OpenCTD

In 2013, Oceanography For Everyone developed the framework for an open source CTD that could be utilized for shelf monitoring applications down to 140m (Thaler and Sturdivant, 2013). The OpenCTD is driven by the Arduino-compatible Qduino Mini, utilizes three DS18B20 steel clad temperature thermistors, a MS5803-14BA pressure sensor, and the programmable and user-calibrated Atlas-Scientific K1.0 Electrical Conductivity Kit. The electronics are held and potted into place using a 3D-printed cap and marine-grade epoxy, and the main body consists of a polyvinyl chloride (PVC) tube closed off with a gasketed plumbers cap. Raw conductivity, temperature, and absolute pressure are printed to an appended text file on a microSD card and the system is powered by a rechargeable 3.7v lithium polymer (LiPo) battery. Parts can be purchased from several online electronics retailers and the local hardware store, while 3D printed parts require a 3D printer capable of a high percentage of infill. Depending on tool availability, construction of a basic model can cost anywhere between 300 - 400 USD.

The OpenCTD has gone through several iterations since 2013 and has been tested through profiling applications in the Great Lakes and as a moored instrument in a tidally-influenced area during Hurricane Hermine (Thaler et al., 2018). Recovered temperature data has been within manufacturer specifications and compares reasonably well with shipboard sensors, despite the slow response and sampling rate. Profile descent rate does play a significant role in this comparison. Hurricane Hermine data suggests that the sensor is capable of measuring minor and major changes in salinity. However, without a nearby device for comparison, the accuracy of the salinity data for the stationary Hermine deployment is called into question. Accuracy for the conductivity sensor relies largely on the effectiveness of the two-point calibration performed by the user and the accuracy of the measured temperature (Thaler et al., 2018). Table 1.2 displays the capabilities of the OpenCTD as determined by sensor manufacturer specifications.

Figure 1.2: OpenCTD Build Progression



The current version of the OpenCTD (far right) is approximately 5cm in diameter and 20cm in length (Thaler et al., 2018).

Table 1.2: OpenCTD Specifications

Specification	**Value**
Conductivity Accuracy	2%
Temperature Accuracy	0.5 °C
Pressure Accuracy	-150 to 20 mbar
Theoretical Maximum Depth	140 m
Limiting Sensor Response Time	5.9 s
Limited Sampling Rate	1Hz

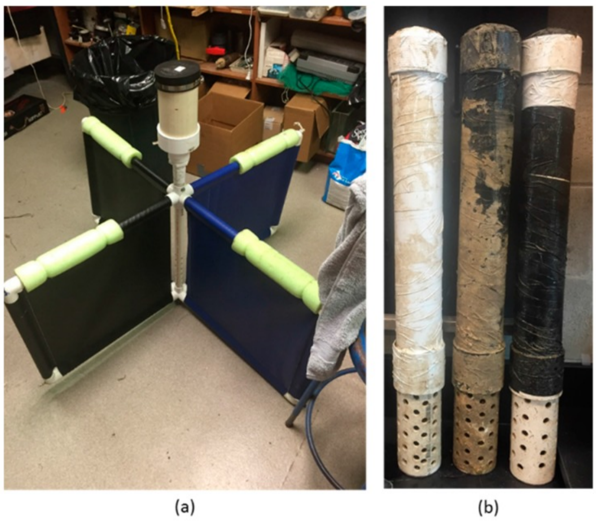
The listed sampling rate is compiled from the sensor response times and physical sampling rates. The slowest of the sensors determines the sampling rate. In the case of the OpenCTD, the physically slowest of the sensors is the conductivity probe, which is only capable of taking a reading once every second. Given the limiting sensor response time of the temperature sensor, the sampling rate may be most effective at 8Hz, but because the device is physically limited by the conductivity sensor it must be set at 1Hz. (SBE, 2017; Thaler et al., 2018).

1.5.2 Arduino-Based Sonde

An open source Arduino-based Sonde was developed in 2016 for drifting and surface moored applications (Lockridge et al., 2016). For surface applications, knowledge of a specific depth is not needed and as pressure does not play a significant role in the salinity calculation at near-atmospheric pressure, the pressure sensor was not needed. The drifting version utilized a GPS unit that also included a real-time clock, allowing the unit to record its location and accurately keep time. The moored version removed the GPS unit and included modified code that enhanced battery life. Both versions began printing data to a microSD card in the comma-separated variable (CSV) format as soon as power was supplied, requiring the end user to sift through data to obtain the desired information.

The Arduino-based Sonde was developed for a study that compared the effectiveness of open source instrumentation against commercial counterparts. Six drifters were released to monitor salinity and temperature variations in Mobile Bay, Alabama and drifted anywhere between 4 to 24 hours, sampling at a rate of 1 Hz. Two moored sondes were installed at different locations within the same bay and were deployed for 24 days, sampling once every thirty minutes. Findings showed that the Sonde sensor suite is effective at examining environmental changes in temperature and salinity. The devices maintained an error level of 0.15 °C for temperature and 1.35 PSU for salinity, both within manufacturer specifications (Lockridge et al., 2016). Although the accuracy may be unreasonable to some, the needs of the study ultimately dictates the need for sensor accuracy. Table 1.3 describes the manufacturer specifications of the Arduino-based Sonde.

Figure 1.3: Arduino-based Sonde



Drifter (a) and moored (b) versions of the Arduino-based Sonde (Photos from Lockridge et al, 2016).

Table 1.3: Arduino-based Sonde Specifications

Specification	Value
Conductivity Accuracy	2%
Temperature Accuracy	0.2 °C
GPS Accuracy	3 m
Clock Accuracy	1 ppm
Limiting Sensor Response Time	1 s
Limited Sampling Rate	1 Hz

1.5.3 An Open Source CTD For Everyone

The OpenCTD and Arduino-based Sonde both provide reasonable foundations for tools that could be built by your average high school student, citizen scientist, educator, or fishermen and compare admirably to commercial counterparts given their low-cost nature. As hands-on education and experiential learning is becoming more of a common place in the classroom, it is believed that the OpenCTD could be suitable tool for scientific research, education, and public outreach (Thaler and Sturdivant, 2013; Thaler et al., 2018). In theory, this holds true for those that are already knowledgeable in introductory oceanographic concepts or have a knack for tinkering, but not for those with no prior experience in such areas. At first glance, the OpenCTD framework assumes that the end user is capable of finding information and additional guides where applicable, and as such glosses over many key concepts needed to understand and construct an open source CTD. Those that do not possess moderate computer skills may find data access and interpretation uncomfortable (Kuonen, 2018).

As part of this research an open source CTD, dubbed the CTDizzle, was developed and retrofits more scientific and technical information into the OpenCTD framework to create an improved system. This was done in order to reassess its educational and public outreach potential. The CTDizzle was utilized as the central component in a pilot study in the Newport, Oregon area to 1) engage coastal high school students in technology-centered marine STEM, and 2) support cooperative research with commercial fishermen. The idea stemmed from literature previously reviewed, utilized modified tools developed from a multitude of studies, and pulled from technological and engineering processes that have been rooted in oceanographic, educational, and cooperative research for many years.

1.6 Objectives of This Research

Experiential learning theory places emphasis on the significant role that experience, the act of performing an action or working with something first hand, contributes to the learning process (Kolb et al., 2011). The OpenCTD and Arduino-based Sonde platforms provide methods for reproducing a low-cost environmental sensor and both sets of authors have alluded to the use of an open source device as a tool for ocean education and outreach (Thaler and Sturdivant, 2013; Lockridge et al., 2016). With the success of marine education programs developed by the MATE Center and cooperative research endeavors with fishermen across the globe, this research initiated a small-scale study centered about an open source CTD. The desired outcome was to explore if an open source oceanographic instrument could be a suitable tool for increasing interest in and understanding of STEM, the ocean, and related careers, as well as support fishermen's interest in participating in cooperative science. As such, this research was governed by the following overarching question:

Will a learning experience centered about the building, modification, and utilization of an open source oceanographic instrument influence an individual's interest in and understanding of the marine environment?

This overarching question was then split into two sub-questions which give way to the primary objectives of this study.

1. *Will a learning experience centered about the building and modification of an open source CTD positively influence a coastal high school student's interest in marine STEM education and related careers?*
2. *Will the use of an open source CTD and produced instrument data positively influence a commercial fisherman's interest in cooperative research and data?*

The first primary objective was to engage coastal high school students in marine STEM through the construction of an open source CTD and concurrent experiential activities. Effort was also made to introduce students to conceptual and hands-on STEM and SCANS skills that they could utilize and hone in the future. The premise was that the act of building the CTD, designing accessories, participation in facility tours, and the presentation of work at conferences would increase student interest in marine STEM education and ocean-related careers.

The second primary objective was to then engage commercial fishermen in cooperative science through the deployment and use of student constructed CTDs. The premise was that the collaborative development of CTD accessories, deployment of the devices, and access to recovered data would increase commercial fishermen interest in continued scientific cooperation and the use of data for decision-making.

With respect to open source oceanographic instrumentation, both the OpenCTD and Arduino-based Sonde foundations are reproducible and can be utilized to monitor the salinity and temperature of seawater in Eulerian or Lagrangian applications (Lockridge et al., 2016). However, both builds require a user to learn a variety of technological skills and marine STEM subjects. It is easy to assume that an interested individual or group may already possess the skills or know where to access information needed to construct an open source CTD. This may not always be the case. The end user could be an educator interested in incorporating environmental data collection into the classroom, an early-career scientist looking for a low-cost way to perform experiments, or a kayaker who is simply curious about the physical world. Therefore, a secondary objective of this study was to further develop an easily followed and understood open source

CTD framework that could be implemented, modified, ripped apart, and improved upon by any user for any application.

The remainder of this thesis will address the overarching question and sub-questions. Definitive answers to the sub-questions will provide a basis for answering the overarching question in future studies. Methods, results, findings, and conclusions are expounded upon in further chapters. Confirmation of positive influence for both objectives would suggest that an open source CTD and the surrounding experience would be a suitable method for engaging students and fishermen in marine STEM and cooperative science, as well as providing a path for furthered understanding of the marine environment and enhanced ocean literacy.

Chapter 2
Methods

2.1 Further Development of an Open Source CTD

Building off of the OpenCTD framework, an open source CTD was developed in an effort to make a more accessible, repeatable, and modular CTD for students, educators, and general users. Another goal was to keep cost low while creating a robust device for utilization in adverse environments. The SparkFun DeadOn RTC Breakout was added, allowing the device to maintain time when primary power was not supplied (Dallas Semiconductor, 2010). Time is arguably the most important parameter in any dataset as it allows a user to determine when an event occurred (Willassen, 2008). A two-inch Blue Robotics watertight pressure case and compatible temperature sensor, pressure sensor, and external switch were also implemented (Robotics, 2017). The temperature sensor was upgraded to the TSYS01 allowing for higher accuracy measurements, while the pressure sensor was changed to the MS5837 for the increased depth rating (TE Connectivity, 2015b,a). Both sensors are impregnated in a compatible Blue Robotics bulkhead by the manufacturer for the added simplicity of integration into the pressure case and CTD package. The addition of the external switch allowed the device to be turned on and off after each use without compromising the case seal. Modified software allowed data to be stored in sequentially named files after each power cycle. The Arduino MKRZero microcontroller was implemented to allow for the addition of data conversion algorithms for depth, salinity, and density anomaly with output to the printed CSV file. The end result of the redesign process was an open source CTD that maintained moderately faster response times, was theoretically suitable for shelf profiling and time-series applications down to 200m, and had an enough room left over for future expansion. Users would no longer have to worry about processing the data or writing code, but could instead focus on the building of the instrument and analyzing the resultant data. Figure 2.1 shows a picture of the redesign utilized in this study. Table 2.1 describes the compiled manufacturer derived specifications of the CTDizzle.

Figure 2.1: Completed CTDizzle

Each CTD has an approximate diameter of 6cm and length of 22cm.

Table 2.1: Compiled CTDizzle Specifications

Specification	**Value**
Conductivity Accuracy	±2%
Temperature Accuracy	±0.1 °C
Pressure Accuracy	±100 mbar
Time Accuracy	2 ppm
Theoretical Maximum Depth	200 m
Limiting Sensor Response Time	1 s
Limited Sampling Rate	1 Hz

Sampling rate is determined by the slowest of the three sensors, which in this case is the TSYS01 temperature sensor in combination with the Blue Robotics bulkhead. A time accuracy of 2ppm roughly translates to 64 seconds of drift over the course of a year.

The CTDizzle was tested against Seabird Scientific and YSI CTD variants over the course of the study to determine the accuracy and effectiveness of the sensor suite. Initial tests suggested that there is a large human error component in the accuracy of the conductivity sensor due to calibration methods and temperature compensation algorithms. Currently, a comparison test is underway to hone in on the effectiveness of the conductivity circuit temperature compensation and to see if a linear compensation equation in post processing may be more applicable. This information will be utilized to develop a more robust quality conformance testing process for future versions. A complete comparison will be submitted to a journal after final submission of this thesis.

2.1.1 Build Guide and Repository Hosting

Prior to conceptualization of this study, the build guide for the first version of the CTDizzle was written with the general public as the intended audience. After determining that this project would be implemented into a high school STEM classroom, it was modified to encompass the newest version of the CTD and introduce students to several technical and conceptual STEM topics and skills. These skills are key to understanding oceanographic instrument construction, utilization, and data analysis (see Appendix A,C). Within the guide, there were brief explanations for certain subjects or direct links to tutorials and websites that provided additional information (Table 2.2). The guide also incorporated concepts of engineering design, relationships, and electrical fundamentals as described by the NGSS (HS-ESS3-4, 4-ESS2, 4-PS3-2) and followed most emphasis guidelines stated by the National Science Education Standards (NSES, pg.52). The first version of the build guide established a starting point and left room for educators to expand given the varied interests of students.

GitHub is a software development platform that allows users to create and modify source code, libraries, and repositories for a number of programming languages and projects. GitHub was utilized as the primary location for the build guide, pinout guide, materials lists, and supplemental documentation of the CTDizzle (Appendix C). Additionally, the build guide incorporated materials developed in this study that are hosted on platforms such as Google Sheets and YouTube. The goal of hosting the project on these websites was to create a free and accessible environment, allowing anyone to find and utilize the contents.

Table 2.2: Topics Covered In Original Guide

Science	**Technology**
Pressure	Arduino IDE
Temperature	Time/Frequency
Salinity	Serial Communication Protocols
Archimedes' Principle	File Reading/Writing
Yaquina Bay	Data Analysis
	Calibration
Engineering	**Mathematics**
Soldering	Unit Conversion
Breadboarding	Pressure to Depth Relationship
Electrical Fundamentals	C,T,P to Salinity
Galvanic Corrosion	
O-Rings	
Case Design	

2.1.2 Data Processing Options

Despite the design and source code for the OpenCTD being freely available, the system lacked a provided data processing method for raw conductivity, temperature, and pressure data. The onus of accurately and concisely creating understandable data was placed on the end user. To reduce this need, three data processing methods were created for a mixed array of end users. These methods utilized computational algorithms based on the 1978 practical salinity scale (PSS-78) and the 1980 international equations of state for seawater (EOS80) (Fofonoff and Millard, 1983). MATLAB was utilized to create a script that would process the data and output profile plots, time-series plots, and a data table for any academic users. The *deploytool* function in MATLAB also allowed the creation of a standalone application, which non-MATLAB users could install on a computer and utilize for data analysis if their file matched the same format utilized in the script. An R script was also written for those who wished to maintain the open source nature of the project and who were willing to learn how to use the R environment. Finally, a Google Sheet was created that users could copy data into, which would then output processed data in tabular and plot form. This was viewed as the method that schools would be most accustomed to as spreadsheet style programs are common in the classroom. Computational algorithms were also built into the Arduino operating code of the open source CTD, thus allowing end users to view relevant data or plot data themselves without the need to run it through complex processing.

2.2 Working With Coastal High School Students

2.2.1 School and Student Selection Process

Prior to this study, the CTDizzle, or any open source CTD variant, had not been implemented in the classroom. During the development stage of this study, the original idea was to enlist schools that were both near Oregon State University (OSU) and coastal, largely due to the availability of time and travel distance. Several teachers at high schools along the central and southern Oregon coast were contacted either during conferences or via email and asked if there was interest in participating in the study. While the majority showed interest, there was little follow up response after secondary contact. Factors, such as teacher and personnel turnover, prevented some teachers from committing to full participation and implementation of the project. During the OSG sponsored 2016 State of the Coast (SoTC) conference, a science teacher from Toledo High School (THS) in Toledo, OR became interested in the project and agreed to see if it could be worked into their lesson plans. The teacher's previous working relationship with OSU researchers was a factor in obtaining their commitment. Due to timing issues and lack of additional interest from other high schools, Toledo High School became the sole school participating in this study, thereby making this a convenience sample (Etikan et al., 2016).

Due to scheduling issues with the original THS science teacher, the project was then transferred to the Career Technical Education (CTE) teacher at the same school. This CTE teacher initially selected 8 students that they felt would benefit from a project of this type, believing that they were unable to include all thirty of the students from the original class period. These eight students were chosen based on the teacher's judgment, with the intent of creating a group of students that had a diverse range of interest in STEM, connection to the ocean, experience with tools and research, and social standing within the student body.

A week prior to beginning the study, students were given assent forms and parental notifications of research (per Institutional Review Board requirements) (Appendix B). At the start of the study, all 8 students had signed assent forms and delivered parental notifications to guardians. All participated in study activities and completed the pre-assessment and post-assessment questionnaires.

2.2.2 Researcher Presence

The CTDizzle project was originally intended to be a self-guided project, in that students could find all necessary instructions and information through the GitHub repository. Teacher support was expected to be minimal, mostly in the form of answering student questions and providing brief instruction for hands-on skill development. Due to timing and the uniqueness of the project, implementation of the CTDizzle required some external support from the researcher. In an agreement between the teacher and researcher, the researcher attended the class on a bi-weekly basis to observe student progress and provide support in the form of technical and scientific expertise. With consideration for activities that occurred outside of the classroom, researcher-student contact time was approximately 80 hours over the span of 25 weeks.

2.2.3 Student Experiential Learning Activities

Construction, Accessorization, and Testing of the CTD

At the beginning of the study, students were informed that local fishermen would be utilizing the CTDs at the beginning of the crabbing season, giving them approximately 11 weeks to construct the devices. Seven of the students were initially tasked with constructing four open source CTDs and assigned themselves into two 2-person groups and one 3-person group. Each group initially focused on the construction of a single CTD, involving all aspects such as soldering, potting, and programming. The remaining student worked alone to design a clamp that would allow the CTDs to be quickly and efficiently attached to a crab pot.

The build guide for the CTD was written to not only provide a map for constructing the device, but to also introduce students to a variety of STEM topics through written and linked examples, including general oceanographic concepts and issues encountered when developing and deploying marine instruments (Appendix C). It was designed so that students could gain a basic understanding of a topic, apply learned information, and perform the work over 1-2 week intervals. Preparatory soldering, breadboarding, the Arduino Integrated Development Environment (IDE), and electrical fundamentals were designed to take approximately one week each, while activities such as primary soldering, potting, and code analysis were to take two weeks each. Given the 50 minute class period, 10 minute start-up and break-down times, and the periodic holiday schedule, 25 hours of build time was designed in as a "best-case scenario" for student completion of the devices. After 10 weeks, students were to have working prototypes completed so that the final week could be used for student designed tests, experiments, and introduction to basic oceanographic concepts. If prototypes were not completed in the allotted time, all unfinished tasks were completed by the researcher.

As a method for learning introductory topics, students performed two functional checkouts of the CTDs during the study period. For the first test, a 10m tall 4-inch PVC pipe was filled with water and students lowered the CTD to the bottom to test the pressure sensor. Prior to performing this test, students were handed worksheets that explained concepts such as Archimedes' Principle, salinity, temperature, hydrostatic pressure, and density (Appendix A). From these worksheets, students calculated how much water was needed to fill the pipe, determined whether or not the CTD would sink under its own capacity, and the expected hydrostatic pressure at the bottom of the pipe. For the second test, students placed a CTD in Yaquina Bay to check the functionality of the device in a real environment and to use collected data in analysis exercises and presentations at conferences.

Instructions in the build guide were written assuming student interest would be uniform across all topics. After student pre-assessment questionnaires were received, they were analyzed to determine student areas of interest in the project. The build guide was adapted and supplemental materials were created to expand on those areas of interest. Throughout the study period, the build guide was edited to improve on sections where it was perceived students were struggling or at the students' request for additional information.

After the first few weeks of construction, it was apparent that students were struggling with some areas and would not reach the CTD quota. At the suggestion of the teacher, student groups arranged themselves so that each group would focus on a particular aspect of the manufacturing process and share duties similar to an assembly line. Due to delays in the crabbing season from domoic acid prominence and contract disputes, the crabbing season was delayed several times which extended the amount of construction time by two weeks, resulting in approximately 13 weeks (or 30 hours) of total working time.

Tours

In addition to working on the CTDs, the researcher designed in two tours that introduced students to two different career areas within marine STEM. The first tour occurred aboard the Research Vessel (R/V) Sikuliaq while it was stationed in Newport, Oregon. The R/V Sikuliaq is a University-National Oceanographic Laboratory System (UNOLS) vessel owned by the National Science Foundation and operated by the University of Alaska Fairbanks. It has ice-breaking capabilities and is primarily utilized in Alaska and the polar regions (UAF-CFOS, 2018). Stationed in Newport at the time, the vessel was utilized by Oregon State University (OSU) to perform Ocean Observatories Initiative (OOI) operations and the captain allowed a tour of the vessel for the eights students participating in the CTD project in addition to another STEM class. Students received a tour of the aft deck, galley and scullery, staterooms, infirmary, and bridge from the 2nd mate. During this tour they also interacted with a marine technician, able-bodied seaman, and the 3rd mate.

The second tour occurred at the Ocean Observing Center in Corvallis, Oregon. The Ocean Observing Center is maintained by OSU and is responsible for the Endurance Array portion of the OOI. The purpose of the OOI is to collect long-term datasets that will provide researchers with data to learn more about topics such as coastal dynamics, ocean-atmosphere exchange, biophysical interactions, and turbulent mixing. Students were given a tour of the facilities, introduced to different observation platforms, and interacted with personnel with backgrounds in engineering, physical oceanography, and technical work.

Conferences

The students participated in three conferences over the course of the project, both as observers and presenters. They first attended the OSG sponsored 2017 State of the Coast (SoTC). The audience at this conference included students, researchers, members of government, fishermen, surfers, educators, and other ocean stakeholders. The students also presented in a panel at the CTE & Industry Summit. The audience at this event was primarily CTE educators and school administrators. Lastly, the students participated in a K-12 poster presentation session at the 2018 Ocean Sciences Meeting (OSM). The audience here was a mix of scientists, educators, administrators, decision-makers, managers, and others with a vested interest in the marine environment.

2.2.4 Data and Analysis Methods

Data collection on the students occurred for 25 weeks, from the day the pre-assessment questionnaire was administered to the researcher's last meeting with the students. Data collected included observations made during bi-weekly meetings, website use tracking, pre- and post-assessment questionnaires, and periodic discussions with the teacher regarding student abilities. The time between administration of the pre-assessment and post-assessment questionnaire was

22 weeks, while observational, discussion, and tracking data was collected for the full 25 weeks.

The pre- and post- questionnaires consisted of a mix of Likert-type statements, multiple-choice questions, and open-ended questions (Appendix B). Questionnaire design was informed by the questions presented on the annual MATE ROV survey (MATE CENTER, 2014). The focus of the pre-assessment questionnaire was to assess student interest in STEM and ocean education and careers prior to beginning the CTD project. The Likert-type questions required students to agree or disagree with a statement at varying levels of intensity. A single multiple-choice question required students to state their interest in continuing their education. There was also one open-ended question that asked students to state a particular aspect or topic they were interested in as it relates to the project. The focus of the post-assessment questionnaire was to assess student interest after participation in the project. The post-assessment questionnaire utilized the same Likert-type statements as the pre-assessment, but with an emphasis on increased interest and perception of knowledge. Multiple-choice and open-ended questions in the post-assessment also focused on how the students perceived the experience, the usefulness of the project, and any difficulties they may have experienced during the project.

Observations were made during the bi-weekly meetings in the classroom, at conferences, and presentations and were gathered via hand-written notes. These notes included direct student quotes and observations regarding progress, tool utilization, student conversations, initiative, and individual student improvement. Apart from the classroom sessions, observational notes were taken at SoTC 2017, the CTE & Industry Summit 2018, and at OSM 2018. Utilizing GitHub's anonymous tracking service, observations were also combined with data on the daily number of unique visitors and page views to formulate a rough metric for student progress and engagement during each stage of the project.

Using the coding concept from the grounded theory approach, common words and phrases of interest were identified in written responses and from verbatim statements (Auerback and Silverstein, 2003). The use of "code" here should not be confused with programming languages like Python or LaTeX, and instead refers to the systematic identification of patterns found in text. Modal statistics were then generated from Likert-type results of both assessments to determine central tendency (Boone and Boone, 2012). A manual content analysis was then performed on the combination of tracking information, observations, and results from the assessments to further assist in the identification of themes, trends, and patterns (Stemmler, 2001). An examination of this information assisted in the generation of an answer for the first sub-question.

2.3 Working With Commercial Fishermen

2.3.1 Fishermen Selection Process

After a brief presentation at a researcher-fishermen meeting for Seacast.org, two fishermen expressed interest and verbally agreed to participate in the project. Per the Institutional Review Board, verbal consent was acceptable and fishermen were not required to sign any forms. The presentation occurred in Newport, OR which is the homeport of both participants. Both fishermen completed a semi-structured exit interview after approximately three months of device deployment and data collection.

2.3.2 Fishermen Activities

Fishermen were asked to take student constructed CTDs and deploy them from their fishing vessels. They had the option of deploying the devices in crab pots for time-series data collection or via line for a profile of the water column. Both opted to deploy the devices in crab pots. A MATLAB standalone application was created so that fishermen could plot the data themselves on a personal computer, but after the first meeting it was agreed that the researcher would perform the data analysis and send information via electronic mail. As US fishermen prefer data in the units of Fahrenheit and fathoms, emailed plots and tables contained this information after noise was removed. Due to electronics issues, the sampling rate for the CTDs was left at 1Hz, but time-series plots were made using 15 minute averaged bins. Fishermen were also asked to keep a log of CTD location deployment. This log contained latitude and longitude, ship depth sounding, the number of crabs the fishermen found in the recovered crab pot, and the at-sea conditions observed. During each meeting, the fishermen were asked what could be done to improve the device and experience. Adaptations were made if the fix could be immediate, otherwise they were noted and are to be considered in the next iteration of the CTDizzle.

2.3.3 Data and Analysis Methods

Fishermen observational data collection began during the Seacast meeting and spanned over a period of 15 weeks. The first set of student constructed CTDs were delivered shortly after the start of the delayed crabbing season. Over this timespan, informal meetings occurred approximately every two weeks to collect recovered devices, redistribute refurbished CTDs, and deliver data products. Meetings either took place at the dock, on a fishing vessel, or at a bay-front coffee house. Observations from these interactions were recorded in a notebook. Due to time constraints on the researcher's behalf, the semi-structured exit interviews for the fishermen were performed after 13 weeks.

Researchers use structured interviews to obtain a certain type of information, and thus questions are very specific and answers can usually be quantified. In unstructured interviews, the interviewer brings up a theme for conversation and only asks questions that maintain that theme (Hove and Anda, 2005). Semi-structured interviews are a mix between unstructured and structured methods, and require the use of both specific and thematic questions. Questions during the exit interview were geared toward the use of the device, data usage, reasons for participation, and overall experience. The theme of the interview was left at the broad topic of cooperative research. Themes and patterns from observations, verbatim statements, and the exit interview were identified and utilized to assist in answering the second sub-question.

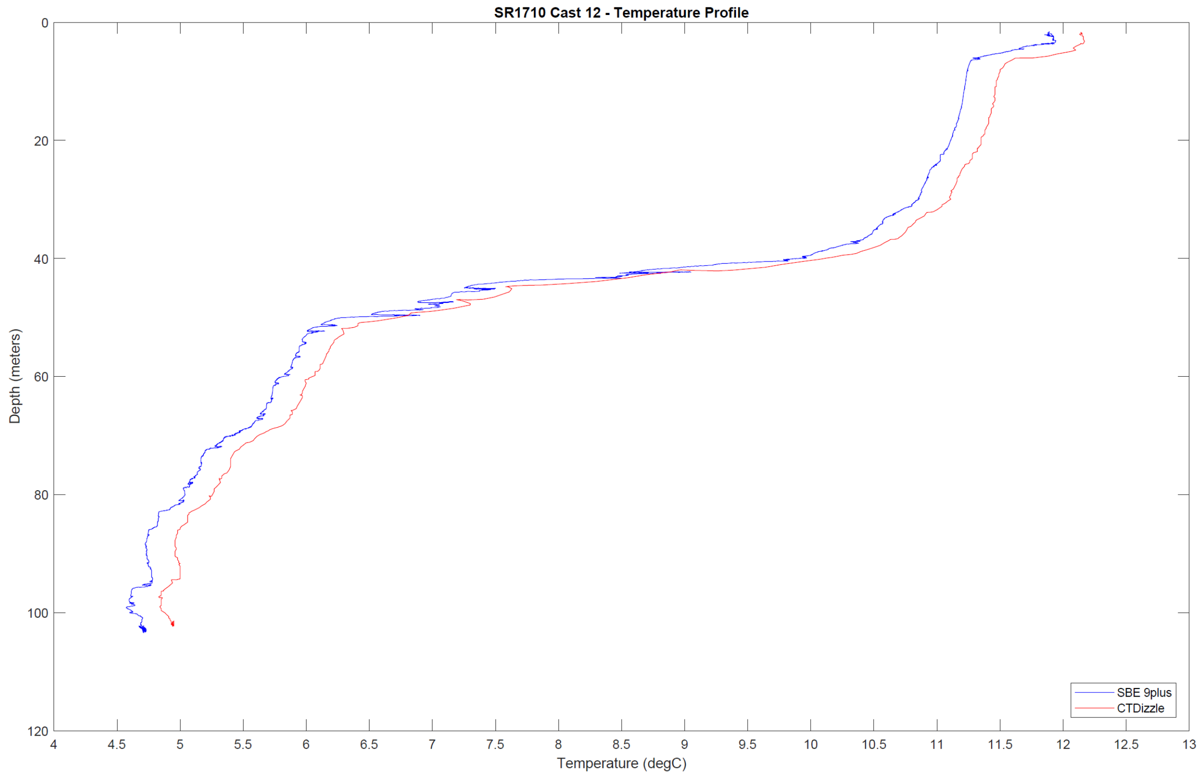
Chapter 3
Results and Discussion

3.1 A Brief Analysis of the CTDizzle

Since its conception, the CTDizzle has gone through several iterations, with each prototype utilizing different sensors, electronics, or materials. The first version was developed in September 2016 and matched very closely in design to the original OpenCTD. The second version of the CTD involved the use of a 3-inch PVC flange, but was never tested. The third version of the CTDizzle utilized the 3-inch Blue Robotics Watertight Enclosure and the same components as the first version, with the exception of the TSYS01, MS5837, and the addition of the DeadOn RTC (Appendix C8). The CTD utilized in this study is considered the fourth version and is a product of a multitude of accuracy, function, and pressure tests that have been performed in estuarine, shelf, and open ocean settings across all versions of the CTDizzle. To date, the researcher has constructed 8 CTDizzles, 5 of which contain the hardware for the most recent version. An additional two were constructed by students at THS and tested with the assistance of Newport fishermen. During testing, two CTDs flooded immediately at depth, and a third lost the ability to measure conductivity. At the conclusion of this study, there remains 4 functional fourth version CTDs.

Profile and time-series comparison tests between the CTDizzle and commercial variants have been enlightening. Profile tests were performed in Yaquina Bay, the OOI Oregon inshore and Washington shelf sites, and Global Station Papa in depths ranging from 10m to 100m. Time-series tests have been performed along the Oregon nearshore, San Francisco Bay, and Yaquina Bay for periods of one hour to 38 days. Many of these tests had clock, battery, software, or conductivity sensor failures, resulting in lost or obviously inaccurate data. Some of the issues were rectified through subsequent changes and tests. For the successful tests, the CTD measured temperature and pressure were generally within manufacturer specifications when compared to both Seabird and YSI/Sontek CTDs. Figure 3.1 shows a temperature sensor comparison performed at Global Station Papa in July 2017.

Figure 3.1: Temperature Sensor Comparison



SBE data courtesy of R/V Sally Ride. The rosette containing both CTDs was lowered at a rate of approximately 1 m/s.

There was no calibration performed for the temperature sensor, as they are stated to be factory calibrated. The CTDizzle is certainly capable of determining the location of the thermocline, but temperature accuracy is largely dependent on the profiling speed and thermal response and may explain larger gaps in comparison profiles. For stationary deployments, the temperature sensor has also been within manufacturer specifications. After conversion of pressure to depth using a standard atmospheric pressure assumption or first measured pressure value, the depth reading has typically been within ± 2m of commercial variants.

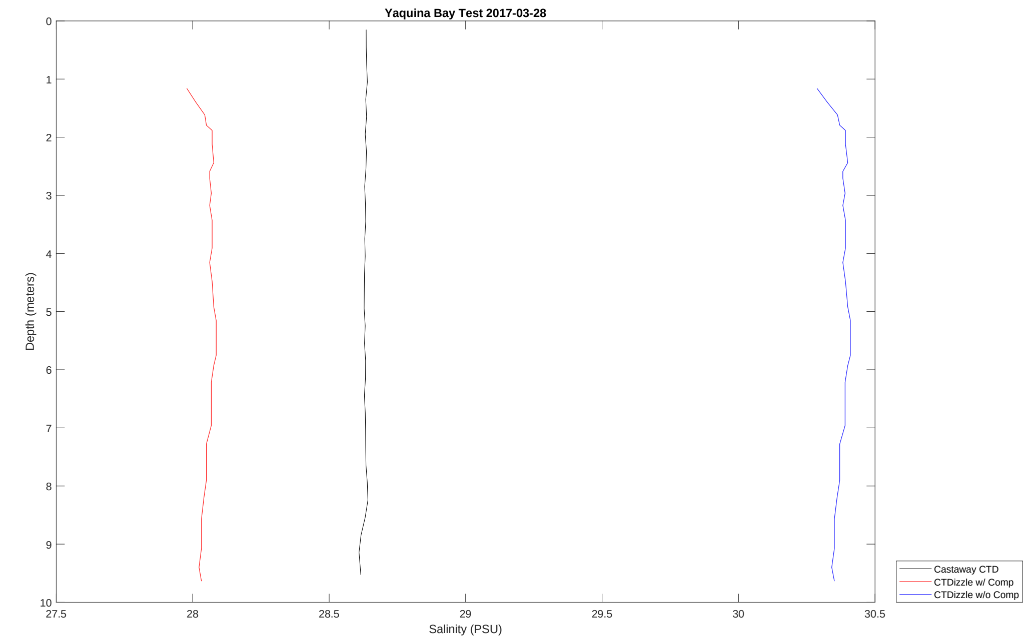
Conductivity (and thus salinity) has been more difficult to rectify, and tests often show conductivity values that exceed the manufacturer accuracy threshold. This is largely dependent on the effectiveness of the user performed two-point calibration and the use of temperature compensation. The two-point calibration for the CTDs was performed with the Atlas-Scientific K1.0 conductivity standards and in a room where the temperature was consistently with 0.5 °C of 25 °C. They were done under these conditions in an attempt to make the calibration procedure easier to perform for users without access to specialized equipment (see Appendix A7).

Temperature also plays a significant role in the conductivity of a solution, the PSS-78 algorithms, and the EOS80 derivations. Inaccuracy in the temperature can lead to the inaccurate compensation of conductivity, which then furthers inaccuracy in the algorithms. The Atlas-

Scientific Electrical Conductivity circuit (EC EZO) has the ability to temperature compensate the conductivity reading and by default is set to 25 °C (Atlas Scientific, 2017). The temperature of the measured solution can be sent to the EC EZO to allow for compensation on the fly. Tests with this by-circuit compensation have been hit or miss, with some tests showing the standard decrease in solution conductivity with decreasing temperature, while others show that conductivity increases with decreasing temperature. This is impossible for seawater applications in the 0 °C to 30 °C range (Sauerheber and Heinz, 2015). This may be due in part from the user-calibration, but also the firmware of the circuit. Figure 3.3 shows an example that utilizes the on-board temperature compensation.

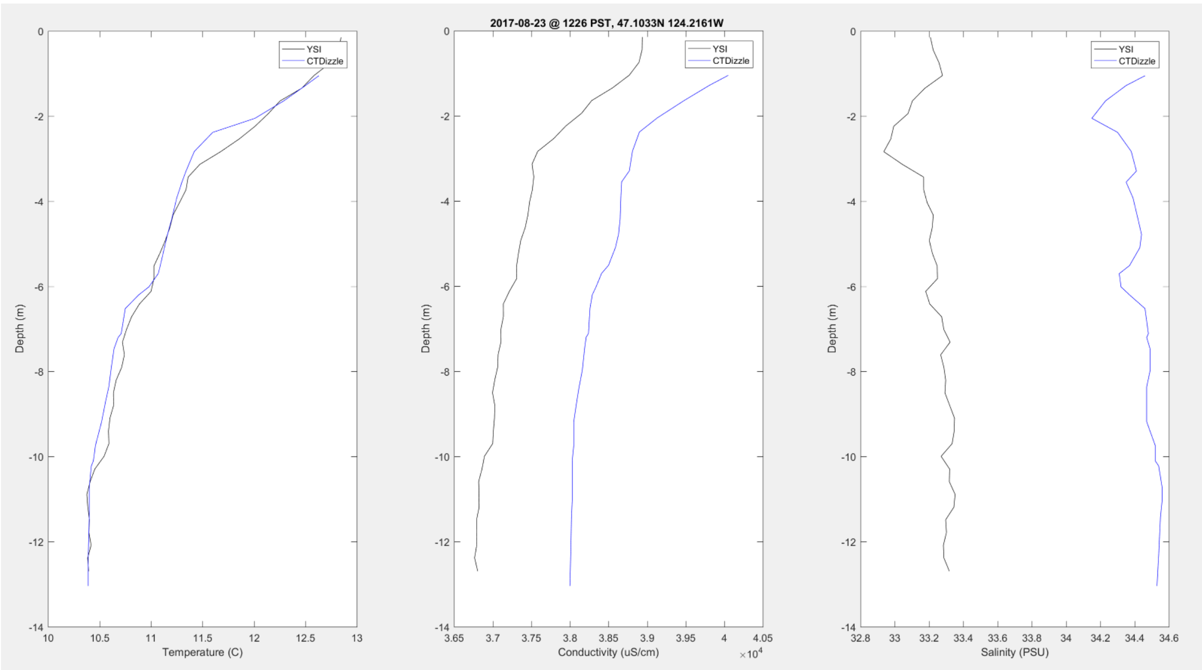
Tests using a common linear compensation equation were also performed (Figure 3.2), but post-processing or on-board calculations have been difficult to utilize due to coefficient variability . The EC EZO default compensation temperature is left at 25 °C and then a linear compensation equation with an arbitrary user determined coefficient is implemented in post processing (Appendix C4, line 49). For most purposes, this linear coefficient can be set to 0.02, as it approximates the non-linear nature of conductivity within reason (Hayashi, 2004). However, manipulation of the compensation coefficient leads to drastically different data. The linear coefficient also appears to be different based on the effectiveness of the calibration. Success for the linear compensation for the CTDizzles have varied by individual CTD, with linear values ranging between 0.005 and 0.2. After significant tweaking, salinity accuracy has typically been between ±2 PSU, which is unacceptable by most standards. As a next step, a more thorough comparison test will be performed to hone in on the effectiveness of the on-board temperature compensation and to see if a linear compensation equation with a static coefficient in post processing may be more applicable. Removing uncertainty in accuracy is absolutely needed for success in generating a viable product.

Figure 3.2: Yaquina Bay - Example with Linear Compensation



Castaway data courtesy of David Noone, OSU. Linear coefficient of 0.01 utilized in temperature compensation formula.

Figure 3.3: Washington - Example with EC EZO Compensation



Castaway data courtesy of Andrew Stevens, USGS. EC EZO temperature compensation utilized.

While temperature was comparative to commercial CTDs, salinity validity was drastically sporadic. Even though sensor manufacturers claim certain accuracy ranges, there are a variety of other factors that impact the accuracy of the end data. For example, calibration accuracy cannot be assumed to be equivalent to dynamic accuracy (SBE, 2016). It is recommended that profiles be performed at a rate of approximately 0.5 m/s so that thermal equilibrium can be reached and at least two samples can be taken for every meter. This ensures that a higher resolution profile is taken. Due to the physical design and lack of development time, the CTDizzle does not take into account factors such as shed wake, unequal sensor response times, thermal mass errors, and whether or not the same water is being sampled at the same time (SBE, 2016). These may be rectifiable in the future, but likely do not have a significant impact on readings due to the already large accuracy ranges of the sensors.

A factor not considered during tests is the effect that electrical noise has on the sensors and microcontroller, which may have contributed to failed tests and wildly inaccurate data. Sometimes the CTD would work well during bench tests, but application in seawater would result in double printing of the conductivity data or values greater by an order of magnitude of what should be expected, suggesting that there was a source of crosstalk between pins or confusion during serial communications. Rapidly fluctuating readings were observed on some of the student-built CTDs, indicating that isolation was needed (Atlas Scientific, 2017). Atlas-Scientific acknowledges that there may be generated noise within the conductivity probe and circuit, and provides the option to purchase a voltage isolator. Future test builds will incorporate a voltage isolator.

Arguably, the TSYS01 temperature sensor and MS5837 pressure sensor from Blue Robotics are capable right out of the packaging, but the conductivity sensor package requires more fine-tuning given the significant amount of human error potential if care is not taken during calibration. The calibration procedure developed as part of this project clearly needs to be revised to improve accuracy and reduce noise, but also needs to maintain a simplistic nature so that calibration can be performed by anyone (Appendix A.7). One possibility is to have a calibration be performed in temperatures equivalent to where the device will be deployed. For example, if it is anticipated that the CTD will be deployed in waters with temperature of approximately 10-12 Celsius, it may be appropriate to perform calibration in a cold room or refrigerator with temperature adjustment capabilities and set the EC EZO default temperature to that of the calibration temperature. As Atlas-Scientific continues to improve the EC EZO and less expensive probes are made available, the CTDizzle will hopefully become a reliable instrument once calibrated properly.

Two CTDs were left at sea for a period of 38 days at a depth of 60m. Upon recovery, the CTDs and the carrying cases were both impacted with sediment. Although one of the devices had a breach in all of the primary o-rings, neither device showed signs of leakage or damage to the internal electronics. This shows that a dual o-ring system has its merits. Inspection of the sensors shows that the conductivity and temperature sensors can withstand abuse experienced during a long term deployment, but the pressure sensor may not be as robust. On one of the

MS5837 pressure sensors, the hermetically sealed gel capsule that protects the sensor had worn away, presumably from sedimentation. The other CTD pressure sensor showed no signs of wear. Possible solutions to this issue may be to tape over the sensor, or utilize a grease such as Dow Corning #4 or AquaShield to prevent abrasion.

3.1.1 Evaluation of the Secondary Objective

The use of the CTDizzle in applications that require high accuracy is not recommended. Although not a primary target for testing in this research, it is clear that the CTDizzle is not yet a suitable tool for scientific research in its current state, but other studies suggest that an open source device could reach that potential (Lockridge et al., 2016; Hund et al., 2016). As sensors become more low cost and accurate, this may change. However, the redesign process has brought with it many additions that are believed to make use easier for end users. Over the last two years bits and pieces of the CTDizzle framework have been successfully integrated into the designs of others, with several more expressing interest in modifying it for new projects (Teague, 2017; Maynard, 2018). From these interactions, it is believed that this research has further developed an open source CTD framework that is modular and easy to follow. Despite difficulties experienced during the prototyping process, the data produced by the CTD is believed to be accurate enough to be utilized for educational lessons without substantial alarm for data quality. Due to the broad amount of information and knowledge needed to build a CTDizzle, it may be an engaging platform that teaches students fundamental technical skills and provides an avenue for learning about the basic physical properties of the oceans. Sections 3.2 and 3.3 of this thesis address the educational and cooperative research potential of a learning experience centered around the device.

3.2 Student Experiential Learning

3.2.1 Student Demographics and STEM Background

The eight student participants chosen by the teacher for this study occupied a mix of grade levels and STEM backgrounds (Table 3.1). As indicated by the teacher, a few of the students had a known direct connection to the ocean. One student was from a local commercial fishing family, another student was from a family that were active recreational crabbers, and the last student had volunteered at the Oregon Coast Aquarium for a summer. As confirmed by the teacher, each student had a smattering of previous experience in areas such as tool usage, electronics, basic mathematics, soldering, and coding. As part of the STEM program at THS, all of the students had previously taken at least one class through the CTE teacher (Table 3.2). The program consists of a variety of required STEM and CTE classes over grades 9-12, but does not have an explicitly oceanic component. The first three years are devoted to providing students a strong STEM background while the last year is utilized by students to pursue an area of personal interest (i.e. chemistry, physics, robotics, biology, etc). Through the program, two grade 12 students had participated in robotics activities in previous years, while a grade 11 student had worked extensively with computer-aided drafting programs. Students within the study had been in the THS STEM program for anywhere between 1-3 years, which suggests that they all had an inherent interest in STEM prior to beginning the study.

Table 3.1: Student Demographics

Grade Level	Number of Students
10	1
11	3
12	4

Gender	Number of Students
Female	4
Male	4

Table 3.2: THS STEM Program Concept

Year 1	Students take one combined science, math, and CTE class taught by two teachers over a two hour period for the full year.
Year 2	Half the students take a CTE class while the other half take a science class for the first semester, then the groups switch for the second semester.
Year 3	Students take a physics class and robotics/electronics class.
Year 4	Capstone year. Students follow an interest (i.e. pure science or pure CTE) for the full year.

3.2.2 Motivation, Progress, and Time

Students were originally given 11 weeks to complete four functional CTDs. Due to delays in the crabbing season, this time was extended to 13 weeks. By the extended deadline, students had completed and tested two CTDs with the unfinished two completed by approximately 80%. The unfinished CTD tasks were completed by the researcher in preparation for the cooperative research portion of the study. Student motivation, initiative, and the occurrence of unforeseen conflicts may explain the lack of achievement of the best-case scenario outlined in Section 2.2.3.

Intended teachings that involved the Arduino IDE, frequency, serial communication protocols, file reading, data analysis, and calibration were cut due to a number of experienced setbacks. However, introduction to these topics still remained in the build guide (Table 2.2). Of the setbacks, the most significant issue was the use of marine urethane that required a limited condition range for curing. Removal of the poured urethane and shipment of the marine epoxy took an additional 2 weeks, which slowed student progress and shifted their focus to soldering the remaining electrical components.

Although it appeared that students were confident in their soldering abilities at the beginning of the study, they observably lacked the necessary fine-motor skills needed for efficient soldering. Over the first few weeks, students could be overheard making comments about the difficulties of soldering header pins to throughholes on the printed circuit board (PCB) and how they had never soldered something that small in previous classes. It was expected that students would finish the soldering of the microcontroller and components over the span of 2 weeks (approximately 5 hours of build time). This did not happen. It became clear that students were struggling with the size of the soldering job and understanding the pinout guide. Additional pictures and video were created to assist students with this endeavor. After a few days of no progress where there should have been some, it became clear that student progress was limited to days when the researcher was present. During days with no researcher presence, student participation was limited as observed from tracking data and progress observed on subsequent visits.

GitHub was utilized as the repository for the build guide and student page use was tracked anonymously through the website's native tracking service. Unfortunately, this service was not discovered until approximately two months into the study, thus data only runs from the end of November until the completion of the student portion of the study (Figure 3.4).

Figure 3.4: GitHub Tracking

There are several points in which student use of the GitHub repository correlates with events and researcher presence. In the workshop where construction of the CTDs took place, there were four workstations, hence the number of unique visitors does not exceed four. On December 5th, 2017 a video was embedded in the build guide that showed students how to connect and solder the conductivity and temperature sensors to the microcontroller. The next day the number of page views and unique visitors can be seen to increase, with a decline in use representing the weekend, followed by an increase in use the following week. On February 1st, 2018 there is a record high number of page views. This is due to students presenting at the 2018 CTE & Industry Summit. During this time, several conversations between students and the teacher suggests that there was a nervousness about presenting and that they were utilizing the build guide to cram information in the event of technical questions from the audience.

As it was intended to be a project operated through student initiative, the researcher was typically in the classroom twice per week. On days that the researcher was present, the number of unique visitors to the repository would be between 2-4 or the number of page views would be in excess of 20. On days that the researcher was not present, there is very clearly a lack of student use of the GitHub repository and progress on the device. Most notably, student progress was limited between November 30th to December 3rd, as made evident by the one unique visitor for that week and a lack of page views. Students were supposedly focused on soldering connections between the microcontroller and the sensors at this time, but most did not solder more than a few connections over the course of those five days, suggesting that there was a lack of engagement when the researcher was not present. It was expected that they should have completed the component soldering by that point in the build process. Teacher presence was minimal during classroom sessions and may have contributed to delayed progress in construction. The teacher would give a five minute pep talk at the beginning of the class period, and then would tend to another class in a different part of the building, only periodically checking on student progress.

Approximately halfway through the study, it was believed that the data and Yaquina Bay topics would have to be cut in the interest of time, so multiple worksheets were created that provided introductory information on temperature, salinity, density, Archimedes' Principle, and hydrostatic pressure (Appendix A). These worksheets were handed to the students in a packet, and they were asked to complete them on their own time to help prepare them for function testing and presentations. They were intended to provide students with a better understanding of how the CTD works in addition to principles that engineers and scientists consider when building and implementing marine instruments.

In order to build off of what the worksheets were introducing, students performed two CTD function checks. A 10m tall PVC pipe was constructed, filled with water, and a CTD was lowered to the bottom. Before this occurred, the idea was for the students to first determine how much water was needed to fill the pipe and then how much salt would need to be added to make the salinity equivalent to standard ocean salinity. Initially, salt was to be mixed in with the water, but logistics, cost, and cleanliness were factors that resulted in only freshwater being used. Second, the students were asked to determine if the CTD would sink under its own capacity. Lastly, the students calculated the hydrostatic pressure the CTD should experience at the bottom of the PVC pipe so that it could be used as a reference for quality conformance. A second check occurred through a deployment in Yaquina Bay, where students were asked to plot collected temperature and salinity over time as an example of data for their conference presentations.

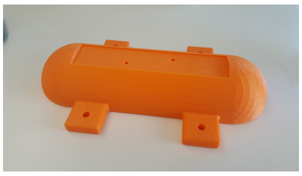
Although students were given the worksheets, there was no requirement that they turn them in. Only a couple students completed them in a timely fashion and were able to apply that knowledge during the function checks. It was observed that progress on the worksheets only occurred when the researcher or teacher was present. Had the students completed the worksheets and been given the opportunity to ask questions about the subjects, the results shown in the post-assessment questionnaire may have been different. It has been found that assigned homework influences learning more positively than no homework. Worksheets and homework have been a key component of the learning environment for decades across all stages of publicly funded education. Previous work also shows that the return of completed homework to the student with comments from the teacher correlates with higher levels of achievement (Paschal et al., 1984). Offering constructive feedback to the students may have also changed the results.

GitHub tracking data paired with observations is clearly not a robust method for determining student engagement, but it does lead to the notion that student attitude and motivation were a function of researcher presence, teacher presence, and accountability. At times there appeared to be no effort on the students' behalf to perform research themselves, which suggests that motivation is also a function of the availability of accessible information and busy work. Instructor personality, authority, and characteristics play a significant role in student motivation, and students tend to learn more from instructors with characteristics that are engaging or align with their own (Wayne and Youngs, 2003). In response to the post-assessment open-ended question asking for project feedback, 50% (n=4) of the students stated that there was a need for more in depth instruction for soldering and circuitry. These responses further outline the importance of an engaging instructor and the use of understandable material when attempting to elicit student interest, understanding, and knowledge retention (Tobias, 1994; Abbasi et al., 2013). Accountability and evaluation are also key influences on student motivation (Ryan et al., 1985). Although there was indication from the teacher to the students that they were to be held accountable for mistakes during the build process, there was no observed reinforcement of the concept of accountability over the study period. Students were also not evaluated through traditional methods such as tests and homework at any point during the study period, so the need to complete the work may have been perceived as unnecessary. Students are more likely to engage in learning if there is a perceived need for effort (Ames and Archer, 1988). Had teacher presence and guidance been more frequent, researcher characteristics been more pedagogical, and evaluation been a component, student motivation to complete the work may have been greater and all of the CTDs may have been completed in the allotted time.

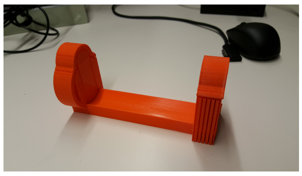
There was an observed dichotomy in student initiative between the student that designed the CTD clamps and the students that constructed the CTDs. The student who spent time designing the crab pot attachment clamp became heavily invested in the project. They often worked on the drawings during the full 50 minute class period. Despite being given examples of common clamp styles used for oceanographic equipment, the student created unique and independent clamps that had minimal teacher and researcher influence. The student ultimately came up with three different designs over the course of the study, all which were 3D printed for fit testing and presentation at conferences (Figure 3.5). None of these designs were utilized to attach the CTD to a crab pot due to time, material availability, or design disproportion. In order to attach the CTDs to the crab pots, both fishermen and student input were utilized to ultimately create a system out of scrap PVC pipe (Figure 3.5d). The student who designed the clamps recognized that water flow was essential for the measurement of water properties and suggested an alternating hole pattern for the PVC enclosure.

Figure 3.5: Clamp/Case Designs

(a) Student Designed Clamp No. 1



(b) Student Designed Clamp No. 2



(c) Student Designed Clamp No. 3

(d) Crab Pot CTD Container

Previous research suggests that interest in a subject can be due in part to a combination of intrinsic motivation and extrinsic regulation, which has lead others to the determine that there is a linear relationship between prior knowledge and the level of interest in a subject (Deci, 1992; Tobias, 1994). Student interest in ocean science and affiliated STEM careers prior to the beginning of the study might be explained by the fact that some of the students had a direct connection to the ocean, had participated in ocean-based lessons in the past, or had prior experiences in STEM courses. From an intrinsic perspective, students may have agreed that they were interested in ocean science and related careers because in the past they may have found an ocean-based activity or lesson to be intellectually rewarding. From an extrinsic perspective, students may have agreed to having an interest because they may have felt compelled to provide an appropriate answer. These perspectives are simply examples and determination is outside the scope of this study, but the prior knowledge and interest relationship may in part explain student interest in and understanding of subjects before beginning the study.

3.2.3 Technical Skills

There was an observable improvement in student soldering abilities over the course of the study. At the beginning of the study, the teacher stated that all of the students had some experience with soldering, but this was observed to be limited experience from observation during preparatory soldering activities. Initially, THS provided Weller D550PK soldering guns which proved to be the incorrect tool for the job. Due to the small nature of the CTDizzle PCBs, sensors, and other electrical components, students utilizing the soldering guns would often apply too much solder to a connection or burn wiring insulation during installation. XYTronic 258 soldering irons were purchased for the classroom, allowing students to solder in a much more controlled manner. After many weeks of soldering, student ability improved tremendously. At the beginning, student knowledge was limited, but by the end of the study students could confidently solder two wires together using methods such as the NASA-approved Lineman's

Splice.

During the breadboarding phase of the build process, it was observed that students were consistently connecting pins inappropriately. After several attempts to utilize drawings, students were introduced to the multi-meter connectivity function. For a few of the students, it was observed that the audio and visual cues of the multi-meter assisted in their understanding of how wires should connect to pins. Later in the study, it was also observed that students utilized the multi-meter to ensure that pins were properly connected to their counterparts and that there were no shorts in the system. Projects involving high school robotics have made similar observations with respect to students' improved use of soldering equipment and tools (LoPresti et al., 2010; Verner and Ahlgren, 2004).

During the sensor setting process, AeroMarine Underwater Urethane 75A was utilized as the potting compound for the end caps. After the first pour, it was found that the urethane did not set properly, which resulted in flooding of the first student-constructed CTD during a pressure test. Considered a fluke due to lack of mixing, a student poured another set of end caps, taking care to ensure that mixing was complete and no bubbles were present in the urethane. Allowed to set overnight, it was clear that the urethane did not cure properly for the second time. Another student carefully reviewed the material data sheet and discovered that the curing process required a low moisture environment between 65-75 °F (AeroMarine Products, 2017). The low moisture environment was not previously considered and it was determined that the needed conditions were not readily achievable in the building that CTD construction occurred. After a brainstorming session with the students, Loctite Marine Epoxy was chosen as a reasonable alternative due to its broad applicability in fresh and saltwater environments. Unfortunately, the transition to epoxy resulted in a delay in overall construction, which caused several other key topics to be cut from the lesson plan.

It is clear from these experienced setbacks that proper equipment and facilities are needed when implementing a construction or manufacturing project. Had the proper equipment and facilities been made available at the beginning of the study, students may have been able to complete tasks on earlier dates, resulting in the opportunity to go over material that had been cut. Given the opportunity to go over more material, student interest and engagement may have been different from what was found in the results.

3.2.4 Knowledge and Communication

Knowledge and Understanding

Prior to beginning the study, the majority of students felt that they understood what conductivity, temperature, and depth represented as well as understood the scientific process. After the learning experience centered about an open source CTD, the majority of students perceived that they had a stronger understanding of the same areas. Only one student felt that they had more knowledge of local physical ocean processes after completion of the project (Table 3.3).

Table 3.3: Responses to Likert-Type Statements Involving Understanding

Statements are representative of strongly agree/agree responses.

Statement	**Pre**	**Statement**	**Post**
I have an understanding of the scientific process.	87% (n=7)	I have a stronger understanding of the scientific process.	75% (n=6)
I have an understanding of what scientists use conductivity, temperature, and depth for.	62% (n=5)	I have a stronger understanding of what scientists use conductivity, temperature, and depth for.	75% (n=6)
I have knowledge of physical ocean processes that occur in Yaquina Bay and the surrounding ocean.	12% (n=1)	I have more knowledge of physical ocean processes that occur in Yaquina Bay and the surrounding ocean.	12% (n=1)

The statement involving knowledge of the scientific process when viewed in conjunction with the study activities is a flawed one. There was no reinforcement from the teacher or researcher as to what the scientific process entailed. Had there been more time before the CTDs were delivered to the fishermen, a lesson could have been given on the process of performing an experiment and how to answer a research question. A strong understanding of the scientific process involves an individual being able to state, observe, and analyze a problem and then hypothesize, experiment, conclude, and generalize findings. Lessons and trainings involving scientific process skills have been found to enhance academic achievement and student creativity (Aktamis and Ergin, 2008).

The pre-assessment result that only one student agreed to have knowledge of physical ocean processes that occur in Yaquina Bay and the surrounding ocean was not expected given that THS is located within 8 miles of the ocean and Hatfield Marine Science Center, a facility that maintains several extra-curricular marine activities. This result may be due to the wording of the statement or a lack of accompanying examples for students to use as a reference. The science teacher at Toledo, which many of the students had as a teacher in the past, had incorporated many marine-based teachings in their curriculum and had encouraged students to attend marine-based learning events in previous years. Either students did not retain any information from these teachings, or the students did not make the connection that things such as tides, waves, and salinity are examples of physical ocean fundamentals.

Student lack of perceived knowledge of Yaquina Bay processes after completion of the project is a fault of course design, student motivation, and time. Students struggled for quite some time on soldering and had some difficulty understanding circuitry directions which resulted in many other intended lessons being delayed or cut entirely, including in-person lessons that would have utilized local marine environment aspects such as Yaquina Bay. The drafted temperature and salinity worksheets introduced students to the Yaquina Land/Ocean Biogeochemcial Observatory (LOBO), a moored platform placed in Yaquina Bay between 2007-2013. Data from this platform is still available today and allows individuals to view, plot, and download data such as salinity, temperature, nitrate, oxygen, chlorophyll, and phosphate over time or with respect to another variable. In the worksheets, students plotted salinity and temperature over time and were asked to look at changes over tidal cycles and with river flow using information from the NOAA Tide and Currents portal and the USGS Water Data portal. Due to infrequent researcher presence during the week and lack of teacher presence during the school period, the majority of students did not complete the worksheets. Exposing students to the material at least ensures that there is opportunity for it to influence their interest and understanding. Had an effort been made to ensure that the students completed the worksheets, the results may be different for the areas dealing with student perception of knowledge.

Students also responded to a series of multiple-choice and open-ended questions that focused on student opinion of the project and perceived usefulness of the experience (Table 3.4). For many of the questions, themes between students were weak and rarely did more than two students share similar responses. In addition to the Likert-type responses, 37% (n=3) students commented that this project did not teach them much about Yaquina Bay and the surrounding ocean. 62% (n=5) of students stated that they now understood that some fishermen are interested in environmental data and that water conditions impact where crab reside. With regard to the perception of data and uncertainty, 50% (n=4) of the students felt in some capacity that this project gave them a better understanding that the sensors they built are not perfect, but the data could still be useful.

Table 3.4: Post-assessment Multiple Choice Responses

Question	**Response**
Do you think the OpenCTD project introduced you to a skill that you could apply in the future?	100% (n=8) stated Yes
Do you think the OpenCTD project opened up other career or education opportunities for you?	50% (n=4) stated Yes
How would you rate your overall experience?	50% (n=4) stated Excellent

Student perception of knowledge and understanding increased in areas where there was repetition of material. Most notably, understanding of the uses of conductivity (C), temperature(T), and depth(D) increased among the majority of students. The majority of students indicated that they had an understanding of C,T, and D at the beginning of the study, but periodic reminders of the purpose of the instrument and produced data throughout the study period may have reinforced and strengthened that understanding. Repetition is not a key player in helping students with the formation of new knowledge, but can bolster it once created (Rock, 1958). Spaced out repetition may also provide greater benefits to long-term learning for students, more so than mass repetition that occurs over a short period of time (Kang, 2016). This may also explain the observed improvement in student soldering skills over the study period, as soldering practice was spaced out over the study period. However, this may also partially explain the perceived lack of knowledge regarding Yaquina Bay, as related material was introduced over the span of a week and not repeated.

Communication and Critical Thinking

Students participated in three conferences over the course of the study, one as observers and the other two as panel and poster presentation participants. As observers, students attended the SoTC 2017 and observed a diverse number of talks and presentations. These focused on a wide variety of areas such as art, seafood, policy, and technology. From this experience, one student stated that they learned about the legislative and legal procedures behind the development of marine technology and study of the ocean. This shows that this particular student was thinking about other marine-related topics apart from STEM. Students were able to build off of this experience to prepare themselves for the panel and poster presentations they participated in during later months.

The students presented in a panel for the two day CTE & Industry Summit 2018. The students split themselves into the groups that they had been working in during the study period. One group introduced the project, the sensors, soldering, and the data the CTD produced. Another group focused on the potting of the sensors, the design of the clamp, the pressure tests performed, and the calculations done to determine CTD buoyancy. This presentation was technical and showed a level of retained knowledge with respect to design and instrumentation. A third group focused on the end product and the relationships fishermen have with the ocean and talked briefly about the localized learning aspect of the project. The final group was comprised of two female students who talked primarily about their interest in STEM, the issues that women face when learning or working in such areas, and why more females should be in those fields.

During day one, attendance to the presentation was low, which first eased the nervousness of the students. Prior to the summit, it appeared that student motivation and retention was low based on observations. The level of knowledge the students had at the time of this presentation exceeded expectations. Students were prepared for most questions, showing that there must have been some level of engagement throughout the study period. After the first day of the summit, all of the students had edited their presentations of their own volition as they all felt that they could use improvement. Audience attendance was also low for the presentation on the second day. In this presentation, students also discussed the challenges of the STEM program at Toledo and the influence it had on their work ethic.

The last presentation ended with an in-depth discussion of some of the difficulties the students experienced during the CTD build process and how failure is a part of learning. Students described some of the issues they experienced when creating their presentations, soldering, and potting. The concept of failure, a topic brought up by the teacher during the discussion, appeared to resonate with all the students. There was an understanding that the product they were working on was a prototype and that no prototype is perfect. Using failure as a learning tool can be a double-edged sword. In some ways, it prepares students for the real-world and allows them to learn and grow from mistakes. Failure is a necessary step toward success and can be utilized to emphasize perseverance and the importance of effort (Inspire Foundation, 2010). On the contrary, the experience of failure can reduce student self-esteem, which negatively impacts other aspects of their life. There may also be a pressure to perform at a level similar to peers, or the lack of effort to try may be a function of a perceived predisposition for failure (Sommer, 1984). From observations, it is apparent that experienced failure has had a positive impact on the students understanding of the prototyping process.

During both panel presentations, the teacher talked about the student-to-student support system they had been developing over the years. Minimal funding paired with large class size had made it difficult for the teacher to actively engage every student at the same level in the past. With 50% of the students continuing high school for at least another year after the conclusion of this study, the teacher hoped to turn more experienced and mature students into peer mentors. This project was viewed by the teacher as an opportunity to assist in establishing that, which became apparent approximately halfway through the study. A couple of the grade 12 students took the grade 10 student under their wing and were able to explain certain concepts in a more simplified fashion than what the build guide or researcher could provide. On days that the researcher was not present, another grade 12 student would attempt to motivate the others to continue working. This created an environment where students could interact and bounce ideas off of one another without fear of repercussion or negative responses.

Establishing a mentor-mentee relationship has proven to be valuable tool for academic, social, and behavioral growth. Peer mentorship at the university level has been found to be a key ingredient in effectively engaging undergraduates in their own education (Tremblay and Rodger, 2003). Connections developed between students in high school have also been found to create positive science identities, a sense of inclusion by both the mentor and mentee, and improve school culture (Zaniewski and Reinholz, 2016; Garringer and MacRae, 2008; Goodrich, 2007). In situations similar to what the students experienced during the CTD project, these connections might be incredibly valuable in maintaining a safe and inclusive environment for all. Additionally, the teacher can draw upon more experienced students in future years to assist in teaching and engagement.

Six of the eight students also participated in a poster presentation at the 2018 OSM and were able to explore other presentations and interact with oceanographic instrument vendors. One student expressed that they learned a significant amount about the business and corporate side of oceanography from vendor presentations. Two students also spent a significant amount of time investigating vendor booths and talked with personnel from NASA, EdgeTech, Seabird Scientific, and McLane Labs, suggesting that they may be interested in technology utilized for study of the marine environment. All of the students interacted with a wide range of oceanographers, technicians, policy-makers, and educators during the questioning period of the poster session. After the poster presentation, students were relieved that it was over and stated that they were asked a lot of questions that were challenging and that they did not know the answer to. The two female students that attended the Ocean Sciences Meeting also interacted with a number of well-known and respected women scientists from different areas within STEM and oceanography. They were able to gain a view of what other women do as scientists, researchers, engineers, speakers, and leaders. This introduced them to opportunities that may be available to them in the future.

From the additional comments section of the post-assessment questionnaire, 50% of the students stated in some form that they enjoyed presenting their work at conferences more than they did building the CTDs, which is surprising given observations and the pre-assessment results. Presenting at conferences can play a significant role in student professional development (Mata et al., 2010). By placing them in uncomfortable public speaking scenarios, they were forced to engage the public and apply what they had learned since the beginning of the study. There is also opportunity for students to interact with professionals from sectors they are interested in, which offers a wider view of what is expected of someone in a professional setting. From the observations at conferences, it is clear that student SCANS skills that involved public speaking and critical thinking improved. Participation may have also had an influence on their interest in STEM-related careers.

3.2.5 Interest in STEM Education and Marine-related Careers

At the beginning of the study, most students had some idea of the path they wished to take in continuing their education after exiting the K-12 public school system. At the conclusion of the study, student interest in continuing education changed slightly by individual (Table 3.5). One student who had previously considered university had switched to military. Another student that was previously not sure was considering attending university. A third student that had previously considered the military was interested in attending community college. There was no indication, either in observations or student open-ended responses, as to whether or not the learning experience centered about the CTD had an impact on this change of interest in continuing education after high school. Outside the scope of this study, there are too many familial, social, and financial variables that can impact a decision of this caliber. To make a more robust comparison, the question would need to make reference to the impact of the project on their interest to pursue more education.

Table 3.5: Student Interest in Continuing Education

Continuing Education	**Before Study**	**After Study**
University	3	3
Community College	1	2
Trade School	0	0
Military	2	2
Not Sure	2	1

Prior to the constructing the open source CTD, drafting the accessory clamp, and participating in peripheral activities, student interest varied between STEM topics, as did perception of their own knowledge and skill levels (Table 3.6). In the pre-assessment Likert-type statements, students typically agreed with a statement. Those that did not agree often left a neutral response, with the exception of one student disagreeing that they had an interest in mathematics, another disagreeing that they had an interest in computer science, and two disagreeing that they had prior knowledge about physical processes within Yaquina Bay and the surrounding ocean.

The pre-assessment results were not surprising as the students appeared to already have an inherent interest in STEM and the teacher had pulled them from a STEM course to participate in the study. Many of the students had also previously taken shop-style classes involving welding, woodworking, and power tool use, suggesting that they also had prior interest in working with tools and equipment. The lack of interest in mathematics among the students was also not surprising, as anxiety and negative attitude toward the subject is not uncommon among secondary level students. This lack of interest may be due to a number of factors, including poor student scores reinforcing skill perception, student self-esteem, lack of support from a teacher, or teacher characteristics (Abbasi et al., 2013; Dowker et al., 2016; Mensah et al., 2013).

The pre-assessment also included an open-ended question which requested that the students state an open source CTD concept or topic that they were personally interested in. The responses to this question did not display any common themes shared by the majority of the students. One student offered no response. Another student stated that they just wanted "to work". Two students expressed interest in learning how the open source CTD works from a technological perspective. One student expressed interest in learning more about ocean science careers. Two other students were interested in the data, how to process it, and how it was used in the oceanographic world. The last student expressed interest in learning more about connections between ocean conditions and marine ecosystems.

Table 3.6: Responses to Likert-Type Interest Statements

Statements are representative of strongly agree/agree responses.

Statement	**Pre**
I am interested in designing and building instruments used for data collection.	75% (n=6)
I am interested in science.	87% (n=7)
I am interested in technology.	100% (n=8)
I am interested in engineering.	100% (n=8)
I am interested in mathematics.	37% (n=3
I am interested in computer science.	87% (n=7)
I am interested in learning or working with data.	75% (n=6)
I am interested in learning more about ocean science.	62% (n=5)
I am interested in a STEM career.	87% (n=7)
I am interested in learning more about ocean science careers.	62% (n=5)
I am interested in working with tools and equipment.	75% (n=6)

Statement	**Post**
I am more interested in designing and building instruments used for data collection.	75% (n=6)
I am more interested in science.	87% (n=7)
I am more interested in technology.	100% (n=8)
I am more interested in engineering.	100% (n=8)
I am more interested in mathematics.	25% (n=2)
I am more interested in computer science.	75% (n=6)
I am more interested in learning or working with data.	62% (n=5)
I am more interested in learning more about ocean science.	75% (n=6)
I am more interested in a STEM career.	75% (n=6)
I am more interested in learning more about ocean science careers.	75% (n=6)
I am more interested in working with tools and equipment.	75% (n=6)

After constructing the CTDs, participating in tours, and presenting their work in multiple professional settings, student interest and perceived understanding of fundamental concepts changed in both positive and negative fashions. Statements in the post-assessment focused on the "more" factor. In that the project had explicitly increased student interest in an area or positively influenced their perception of their own knowledge. From this perspective, the majority of students felt that they were more interested in science, technology, engineering, and computer science as a result of the project. Student interest in mathematics was still below a majority, similar to what was observed in Mann's MATE ROV analysis (2011). Again, this might be an inherent anxiety or dislike of mathematics as the math the students worked through consisted of applied algebraic equations they should have all been familiar with from previous courses.

From the 2008-2010 post-competition MATE ROV surveys, 95% (N=220) of teachers believed that the competition enticed their students to learn technical skills (Mann, 2011). Teacher perception of this was not built into the CTD study, but the majority of students agreed that they were more interested in constructing instruments used for data collection, learning with data, and working with equipment. Interest should not be considered equivalent to motivation, but does play a role in the engagement of students. These findings may also indicate that the students taking part in this study are interested in both continuing STEM education or pursuing a STEM career.

Most of the students agreed that they were more interested in STEM and ocean science careers as a result of the experience centered about the building of the open source CTD. This project shares similar hands-on, technical, and professional aspects to that of the MATE ROV program and results appear to be moderately scalable to the compiled competition data outlined by Mann (2011). However, it should be noted that the MATE ROV data consists of students from elementary to university level. A key difference between the CTD project and an ROV project is the final product application. Students that participated in the MATE ROV competition were able to utilize their product for an exciting task and customize it with team flair, further reinforcing learning and ownership of work. Although student constructed CTDs were utilized by local commercial fishermen and some data was shared with the students, the students commented that there was little reinforcement of the end product. This is mostly a function of time for all groups involved. Admittedly, ROVs are much more active, customizable, and engaging than the passiveness of the CTD.

To compare the MATE ROV compiled data and the results from this study, despite the number of participants disparity, 74% of students stated that they had become more interested in pursuing a marine-related career after participating in the ROV projects and competition, while 75% of students in the CTD study stated that they were more interested in a STEM career and learning more about ocean science careers. 83% of students from the 2010 international competition stated that they wanted to learn more about ocean science as a result of the ROV project while in contrast, 75% of CTD project students agreed that they were more interested in ocean science. 33% of ROV students believed that participation had opened up new educational/careers opportunities, while 50% of CTD students believed the same. In hindsight, a pitfall of the comparison to the MATE ROV survey results is in the wording of the statements utilized in the CTD questionnaire. It is assumed here that more interest in STEM careers and learning more about ocean science careers is equivalent to stating there is more interest in pursuing a marine related career. This is a significant leap and any future study should reword those statements to match that of the ROV survey in order to generate a more robust comparison.

One possibility that changes the outlook of the results is that the students did not interpret the directions for the post-assessment correctly, and instead answered Likert-type statements without consideration for the "more" factor. As an example, a student could have read it as "After building/modifying an open source CTD, I am still interested in science". Given this assumption, the results change slightly. A comparison between the pre-assessment and post-assessment questionnaires then reveals that there was no change in student interest in science, technology, and engineering, with a decrease in student interest in mathematics as a result of this project. It would then appear that there was a slightly positive increase in student interest in learning more about ocean science and ocean science careers, while interest in STEM careers slightly decreased. This still leads to the project having a positive influence on student interest in STEM education and marine related careers, but does not carry over to a general interest in STEM careers. To remove confusion, adherence to the survey platforms designed by the MATE

Center would be beneficial, as their surveys have been refined over at least the last 10 years.

Students also participated in two tours over the course of the study period. The first tour occurred on the R/V Sikuliaq, where students were able to interact with a marine technician, the 2nd mate, and the Captain. They gained a perspective of what it would be like to work and live on a UNOLS global class research vessel. Students did not ask a significant amount of questions as many of the presentations by the crew were informative. However, observations also suggest that student interest dwindled after the first half hour of the tour, possibly contributing to the lack of questions. The second tour occurred at the Ocean Observing Center (OOC) in Corvallis, OR. Students interacted with a number of technicians and researchers whose focus was on constructing and maintaining the OOI Endurance Array. They were introduced to a number of platforms including surface moorings, moored profilers, and gliders, as well as the instruments and mechanisms that amalgamated them. Questions during this tour were primarily funding and cost related, such as "How much does this cost?". Students were also interested in the depth certain instruments were capable of achieving, and were able to make connections between topics they have learned to the platforms, such as the relationship between pressure and depth, as well as Archimedes' Principle.

The effectiveness of tours and field trips is up for debate and depends on the purpose of the tour and the desired outcome. Field trips to art and cultural museums have been found to improve student knowledge, critical thinking ability, and historical understanding (Green et al., 2014). Regular trips to science centers have also been found to be effective supplements to student development of scientific process skills (Cigrik and Ozkan, 2015). It has been reported that there is a significant correlation between a science center visit and increased STEM knowledge, interest, and curiosity. There is also a stronger correlation if the visit occurs for a longer period of time or if multiple visits occur (Falk et al., 2014). The tours of the R/V Sikuliaq and the OOC may have contributed to student interest and curiosity, but were not explicitly built into the assessments to offer an explanation for effectiveness. Frequent tours to different sectors may broaden a student's view of career opportunities connected to the ocean, as well as the variety of people and groups that utilize it.

3.2.6 Evaluation of the First Primary Objective

Eight STEM students from THS successfully constructed two working CTDs, designed an untested accessory clamp that would allow the CTD to be attached to a crab pot, attended tours of a global class research vessel and a federally funded scientific initiative, and presented their work in the form of a panel presentation at a regional educator summit and a poster session at the international Ocean Sciences Meeting. To summarize the findings of this research and relate them back to the first sub-question (Section 1.6), results from questionnaires and a number of observations suggest that these experiences had a generally positive impact on the students' interest in STEM education, the ocean, and related careers. Student responses and observations also suggest that student perception of CTD knowledge increased. However, perception of knowledge of physical processes did not, largely due to lack of direct instruction of such topics. There was also an observable improvement in student technical and SCANS skills such as technology use, communication, and critical thinking. To answer the first sub-question, a learning experience centered about the building and modification of an open source CTD may positively influence a coastal high school student's interest in marine STEM education and related careers. However, findings from this study reveal limitations, considerations, and additional questions that must be addressed in the design phase of a similar study before it can be performed and findings be attributed to a larger population.

3.3 Cooperative Research

3.3.1 Salinity, Temperature, and Other Observations

For the second portion of this study, two commercial fishermen from the Newport area assisted in the testing of student-constructed CTDs using their crabpots as deployment platforms and collected salinity and temperature data along the Oregon coast. Both participants deployed CTDs five times over the course of three months. Each fishermen would place a CTD at the end of a crab pot string which allowed them to deploy the devices without significant impact on time and boat function. Each fishermen also kept logs of each deployment location, time, and returned catch. CTD logs were adequately completed, which is consistent with Childress' (2010) observation that fishermen themselves are constantly logging information for reference at a later date. Logs assisted in data parsing and processing, particularly for CTD deployments which had clock or sensor failures.

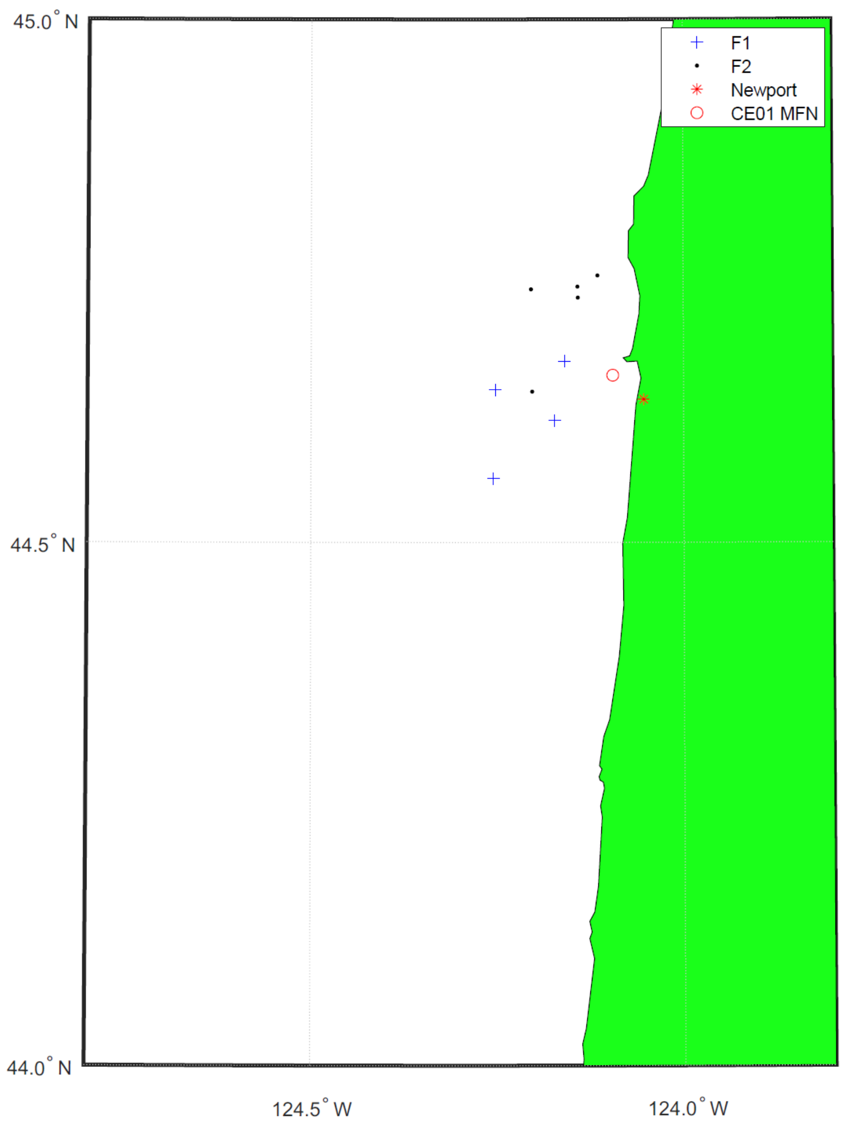
Table 3.7: Compiled Log Data From Deployments

Number of Functional CTDs at End of Study	4/7
Number of Deployments	10
Greatest Deployment Depth	80m
Largest Amount of Crab in Single Pot	30
Average Number of Crab Per Pot	16
Longest Deployment	38 days
Typical Deployment Length	5 days

One CTD flooded prior to beginning the fishermen portion of the study. The other two flooded on the first deployment.

Prior to engaging with the fishermen, it was believed that commercial fishermen were keenly interested in temperature and salinity from the statements of other researchers. The addition of bottom salinity and temperature forecast layers to Seacast.org at the end of 2017 suggested that fishermen had an interest in those variables along the Oregon coast. Fishermen from Cape Cod have also shown interest in temperature and how it relates to Spiny Dogfish distribution, sparking interest in use of the open source CTD as a low cost method for monitoring environmental variables (Maynard, 2018). While salinity and temperature may have initially garnered their interest, at the end of the study both participants stated that they had not looked at the returned plots in great detail. Both of fishermen appreciated the simplicity of using the device, but did not express interest in opening it and pulling the data themselves. There was an understanding that the data from the CTDs was not different from other sources and that no new ground in environmental monitoring was being broken by utilizing the devices. A brief look at the data did make them think a little more about what goes on below the surface, but it appeared that it was not interesting enough for them to utilize in their own analyses or decision making. One fisherman mentioned that bottom salinity in the bay is of particular interest to local seafood processors as many pump this water for use in the plants. This leads to the possible use of a modified open source CTD in other ocean-related sectors.

Figure 3.6: Oregon Deployment Locations



F1 and F2 represent individual fishermen. CE01 MFN represents the bottom sampling package of the inshore Oregon mooring of the OOI Endurance Array. This provided a data comparison point for CTD deployments.

In logs and during meetings, both fishermen noted that there was a substantial amount of sediment in the CTD containers that were placed in crab pots. They expressed how this piqued their interest in the movement of sediment where crab pots were deployed as it was something that was infrequently thought about. The phenomena of "crab pot walking" was also brought up on occasion, showing that fishermen were thinking about the movement of the ocean and how it impacts their gear. This leads to the possibility of gear studies acting as a gateway to other research, such as stock assessment studies.

Shortly after each recovery, fishermen were sent time-series plots of water temperature, salinity, and depth from recovered CTDs as part of the study requirements. Although temperature and salinity were found to not be terribly exciting (no drastic changes over several days), the change in water depth with tides instilled their interest. While tides were generally of concern when crossing the bar and in the bay, they are easily overlooked while on the open ocean. This interest in tides is consistent with previously observed Newport fishermen interest in other physical phenomena, such as currents, surface temperature, wave height, and wave direction (Duncan, 2014). These parameters play a significant role in how they operate on a day-to-day basis and make decisions.

One fisherman decided to toss a CTD in a crab pot off the dock as an experiment. They were interested to see how bottom temperature changes in the bay over time and how it compared to surface temperature. Through a sensor on the hull of their ship, they were able to get surface temperature, but there was a lack of access to bottom data either through shipboard sensors or scientific endeavors in the bay. After recovery of the crab pot, there were two crab that were covered with barnacles. The fisherman explained that this meant that the crab had not gone through a molting stage. When asked if this observation was becoming more prominent over the years, the fisherman stated that it was indeed occurring more during times when crabs should already have molted. This shows the value of LEK and its potential to spur future studies. On more than one occasion, the same fishermen talked about placing a GoPro in a crab pot off the dock. They were curious as to how the crab climbed into the pot and what they did once inside. In short, it became clear that the fishermen that were a part of the study were scientifically minded with respect to their professional activities. They make observations, have questions that can be tested, and are developing possible methods for testing them. This observation is consistent with those from Childress (2010), Duncan (2014), and Kuonen (2018) and could lead to the possibility of more fully collaborative research in the Newport, Oregon region.

Due to the protrusion of sensors and few attachment points for lines and clamps, both fishermen expressed concern with the CTD design. Both offered input on how to appropriately attach the devices to the crab pots, starting with suggestions to utilize bait bags or bins and eventually settled on the possibility of using a PVC pipe with protective foam. They made it clear that deployment and recovery of crab pots was a violent activity and were concerned that without appropriate protection, the sensors would get damaged. PVC containers were constructed using fishermen suggestions (Figure 3.5d). The conversation surrounding the development of the case solidifies that fishermen already have a strong understanding of the ocean and how its processes impact the way they think. Observations involving the case design and conversations involving gear and physical phenomena further show that fishermen knowledge contributed to the project is usually of the technical or operational variety and that researchers are more likely to integrate that knowledge into a study (McCay et al., 2006).

Utilizing fishermen input, either through design involvement or in cost-benefit analysis, has been beneficial to researchers in the past. In gill net fisheries, sea turtle bycatch has been a significant issue. Several methods for reduction have been performed in Baja California fisheries and it was found that fishermen would be willing to use net illumination given that such visual deterrents were low cost, easy to install, and did not significantly impact their ability to catch target species (Wang et al., 2010). Research involving Seacast.org has had similar success in utilizing direct interaction with fishermen to determine appropriate user interface configuration for the forecast site (Duncan, 2014). In conjunction with findings from the Seacast project, it has been found that artisanal fishermen in Zanzibar and South Africa appear to have a preference to use mobile devices over computers to view and input data (Benard and Dulle, 2017; Kumar, 2017). As the end product of both Seacast and the open source CTD project were intended for use by fishermen, it was absolutely necessary to incorporate their perspective into the design process. Although fishermen input on the MATLAB user interface for CTD data processing did not occur, as they stated they did not want to deal with opening the devices, their input was extremely valuable in the physical development of the CTDs.

3.3.2 Community, Communication, and Trust

The theme of the semi-structured interview was set around data and cooperative research. This resulted in a shift in the conversation toward the topic of graying of the fleet, as both fishermen were aware of current studies in the area that were being performed. Both fishermen that were interviewed are from an older fishing generation and are considered to be pillars of the Newport fishing community. However, both expressed concern regarding younger and newer fishermen entering the fleet. Although motivation for fishing is primarily monetary, the interviewed fishermen felt that the younger generations have tunnel vision in this regard and would not participate or consider endeavors that may take away from the potential to make money (i.e. cooperative/collaborative science). A few participants of a pilot study involving graying of the fleet stated that they also felt that economic incentive was a primary motivation for younger generations working in the fishing industry. Among the fishermen in this CTD study, there was the perception that there must be a more explicit positive return for younger generations if cooperative research is to occur. This may be due in part to the older-generation perception that younger-generation fishermen in the area maintain a sense of entitlement (Caracciolo, 2017).

There was no indication as to whether or not either fishermen would converse with colleagues about cooperative and collaborative science. Though the fishermen involved are of an older fishing generation with apparent social pull in the community, it was perceived that the offer of cooperative or collaborative research participation does not extend to the entire fishing community in Newport. That is not to say that there is not a possibility of incorporating more Newport fishermen in research, particularly the younger generation. The concerns of the two fishermen should not be misconstrued as a warning to avoid younger, more gung-ho fishermen. As technology use is becoming more prevalent at younger ages, this leads to the potential for technological research projects to spark the digital generation's interest in working with researchers, particularly if the technology is familiar and interesting (Morris and Venkatesh, 2000).

Although there was talk about maintaining the scientist-fishermen relationship, one of the fishermen also expressed concern over shared use of the ocean and management. They felt that the larger scientific groups in the bay had an air of authority and would look down on the fishing fleet. For example, it was explained that many fishermen had lost crab pots due to scientific surveys off the NH Line. It was concerning to this fisherman that these surveys resulted in loss of gear, especially considering that the ocean is such a large space and that fishing has been a staple for the Newport community for decades. It was also upsetting that there was no reimbursement plan for the fishermen. They felt that this in addition to the lack of communication across the bay was detrimental to the scientist-fishermen relationship. As observed in other cooperative fisheries research studies based out of Newport, communication, trust, and respect are significant factors that determine current and future participation (Conway and Pomeroy, 2006; Childress, 2010; Conway, 2006).

The topic of sensitive information came up during the interview, and opposite to the findings of Childress (2010), there did not appear to be significant concern on the behalf of the participants. Both fishermen were willing to share information such as latitude, longitude, and catch size. However, from the interview, there appears to be a "my area" mentality, where at the beginning of the season fishermen rush to claim a certain area. Once a string is established, other fishermen tend to abide by an implied space agreement, placing their pots nearby, but not too close to cause issue. Both fishermen felt that sensitive information would not be so readily available from younger generation fishermen due to possible distrust of the scientific community or lack of interest in participation.

3.3.3 Cooperative and Collaborative Research in Newport, Oregon

Over the course of the study, both fishermen had described some of the cooperative and collaborative positions they had held in OSU studies in the past. During each meeting, one fishermen would wear a baseball cap that had "Collaborative Research" embroidered on it, further suggesting that there was interest and perceived value in what the scientific community was doing. The offer to continue deploying the CTDs after the conclusion of the study suggests that the fishermen are still interested in allowing the use of their vessels as platforms of opportunity, as similarly observed by Childress (2010). From observations during meetings, it is clear that these two fishermen are not opposed to cooperative science and continued work with scientists, which is consistent with other studies performed in the area.

After the first CTD recovery and data delivery, it was mentioned to one of the fishermen that their crab pots were deployed not too far from a research mooring. In response to this, the fisherman opted to deploy the next set of pots near this mooring so that a data comparison could be performed. Unfortunately, one CTD flooded and the other lost power after approximately two hours and did not record conductivity. Despite technical problems, this shows that the fisherman was aware of accuracy differentials of the prototype CTD and was making decisions that would benefit the project at potential risk to their own activities. In the case of this study, fishermen offered input and made decisions based on their LEK and the confines of the study, without researcher guidance. This study was designed as a cooperative engagement, but leads to the prospect of shifting from fully cooperative to fully collaborative research. Although not explicitly queried, unprovoked decision-making and input in additional areas may indicate a tendency to want to participate in more collaborative research. As discussed by Conway and Pomeroy (2006), the majority of fishermen engaged in the Juvenile Rockfish, Cabezon, and Greenling Collaborative Fisheries Research (JRCGC) project expressed interest in continuing participation, as well as offered ideas for future fishermen-scientist projects. Involving fishermen in every step of the study development process is key to establishing collaborative research. One aspect that should be incorporated into any cooperative research with fishermen is the participant's suggestions for future work. Such information provides future researchers with information on what types of projects fishermen are willing take a role.

In the past, both fishermen had been a part of technological and fisheries-based research. One of the reasons for participation in the project was the participants' general interest in science, as also discovered by Childress (2010). This interest also stemmed to the development of community relationship between scientists and fishermen. During the exit interview, it became clear that the two participating fishermen were not specifically interested in how the CTD data could relate to their fishing activities, but were more interested in collaborating with scientists on projects and developing a community relationship. Similar viewpoints of fishermen from the northeast US have also been observed, in that communication and relationship development have been valued over scientific results (McCay et al., 2006). Fishing is their livelihood, yet there is an understanding that science could help in the future. While the novelty of the open source CTD may have initially influenced their interest in this study, it would appear that participant scientific interest is masked by a general interest in work that benefits the scientist-fishermen relationship. This is not to say that the fishermen did not have a general understanding that there is value in data, but suggests that fishermen value certain aspects of cooperative research over others.

Previous research endeavors based out of Newport have established an array of values held by commercial fishermen. Also from the findings of Childress (2010), Duncan (2014), and Kuonen (2018), one can see that data and validity are valued by some fishermen, but to others communication between study parties is more important. If reasons for involvement are equivalent to the perception of value, then interest in science and enhancing ocean observing data were most valued among participants in Childress' (2010) study. On the other hand, the cooperative or collaborative status of the research appeared to be of value to some fishermen based on the findings of the JRCGC project (Conway and Pomeroy, 2006). While participants in the study outlined by this thesis shared some interest in science-based areas, they appeared to be more concerned about the development of the scientist-fishermen relationship than the availability of data for decision-making. The primary takeaway from this is that the reasons for participation and anticipated value vary from individual to individual and are largely based on the purpose and perceived outcome of a project.

3.3.4 Evaluation of the Second Primary Objective

Themes from an exit interview, in combination with observations, suggest that the specific use of an open source CTD and the data it provides does not positively influence fishermen interest in cooperative research and the use of data in decision-making. Fishermen already have a strong understanding of the ocean as it relates to their practices and based on observations, the impact the CTD had on their interest in citizen science and data use is negligible. Although participants of the study found the CTD data to be interesting at times, there are more accessible user-friendly data and forecast portals with much more useful data. Their interest in citizen science beforehand was not adequately assessed and perceived interest in the data was quickly overshadowed by interest in community relationships. This result provides a different and more complex answer than what was expected. The use of the device was not the reason for interest in cooperative science, but more so of the fishermen's sociological interest in forming relationships with the scientific community. It was the participation in the activity more than the results of the activity that intrigued the fishermen. Additionally, both fishermen understood that the device was just a prototype, but it could potentially provide useful information in the future. Even though it appears to have been a suitable ice breaker, in its current state the CTDizzle lacks the user interface and application potential that could make it attractive for use by the fishing industry.

3.4 Answering the Overarching Question

Prior to the conception of this study, it was stated that an open source oceanographic instrument would be an effective tool for education and outreach engagement (Lockridge et al., 2016; Thaler and Sturdivant, 2013). From this sprouted the overarching question stated in Section 1.6. The pilot study at Toledo High School showed that a learning experience centered about the building and modification of an open source oceanographic instrument can influence an individual's interest in the marine environment. However, it will not significantly influence their understanding of the marine environment unless there is didactic external support, ample educational resources related to key environmental topics, and plenty of time to fathom a deeper understanding of the material. An open source oceanographic instrument has the potential to be an effective tool for education at the high school level, but requires many more conditions outside of the classroom before it can be integrated. An educator can easily select topics from the framework to work into their own lessons, but from this study it is apparent that attempting to incorporate a technology into the classroom without consideration for a longterm end goal is not effective. In the end, this is only detrimental to the students.

Student observations during conferences also describe the potential for a learning experience that provides an individual with a basic background for scientific understanding of the ocean and encourages the learner to think about relationships, other ocean users, and management. This indicates that an experiential learning experience centered about an oceanographic instrument may provide a pathway for the development of more ocean literate students.

Working with the commercial fishermen from Newport showed that an experience centered about the use of an open source oceanographic instrument does have an impact on an individual's interest in and understanding of the marine environment. However, this impact is not based on the science and data as might be expected. Fishermen are already knowledgeable of physical and biological factors of the marine environment, but from this study it is the connections between users of the marine environment that interest them the most. An open source oceanographic instrument also has the potential to be a tool for outreach, but that potential appears to be more in the form introductory platform for communication and trust. The establishment of healthy communication and trust between fishermen and scientists can be seen in the current outcomes of the Abalobi Initiative (Abalobi, 2018; Kumar, 2017). The requirements for successful integration of a technology in the classroom outlined above can also be expanded to successful integration into an industry, particularly the need for supporting roles.

The answer to the overarching question is insufferably cliché. The impact of a learning experience centered about an oceanographic instrument on an individual's interest in and understanding of the marine environment depends from person to person. More information is needed before a definitive answer can be applied, which may not be possible due to the broad nature of the question. The answer relies on many external factors addressed in this thesis, such as individual motivation, prior interest, reasons for participation, and an individual's need to address a question or issue. There are likely other factors not addressed that impact individual interest. Through a grounded theory perspective, new questions can be established that focus on a particular group, technology, or aspect of the marine environment.

3.5 Limitations and Barriers

Integration of a technology into any environment or group requires several ingredients before it can be considered effective and positive. Lessons learned outlined by Valdez et al. (2000) and Byrom and Bingham (2001) make reference to successful integration of technology into the classroom, but translate well to integration into other research projects, particularly those of the cooperative nature. The following list is a combination of those lessons learned with limitations of this study following each point.

1. **Leadership Is Key**
   From the lowest echelon (peers, mentors, teachers) to the highest echelon (administration, oversight groups, government officials) there needs to be individuals that are invested in the integration of a technology.

   Leadership from the teacher in the CTD study can be split into two perspectives; one that involves the large scale integration of the project into the classroom, and the other that involves leadership on a day-by-day basis. From the beginning of the study, the teacher was enthusiastic about the project and what it could provide the students. The teacher took on the role of ensuring that students understood that they were going to present their work at conferences, and invited outside support from school district personnel to assist the students with conference preparation while the researcher was not in the classroom. The teacher also made every effort to promote the project, technology, and collaboration with the university to school officials. However, on a day-by-day basis, teacher presence was limited to only a few moments throughout the class period and was a limitation placed on student progress and motivation. Students were aware of the assigned tasks, but without persistent instructor leadership the amount of work completed was much less than anticipated. Although being made aware of the project and the events that the students were participating in, there appeared to be little support from higher level school officials and administration. Several times over the course of the study, the teacher expressed that there was little support from the school in financing, interest, and logistics when engaging students in the extracurricular activities of the project. This lack of leadership from higher up may have a cascading effect on leadership at the working level.

2. **Humans And Context**

   Learning outcomes are influenced more by human and social environment factors than hardware and software limitations.

   Another limitation was the context and assigned value of the project. As there was no reinforcement and repetition of some scientific concepts, the learning outcomes were not as in-depth as expected. This is shown through the statements of students that wished they could have learned more about Yaquina Bay and the local environment. By reinforcing the use of data and its importance in the understanding of the natural world, the students may have understood the value in technology as well as some context to the environment that they live in. Although students understood that they were building the CTDs for fishermen, the context under which the fishermen were using the CTDs was also not reinforced for the students. Had it been repeated to students the purpose of the devices, either through lessons or direct interaction with the fishermen, this limitation may have not been as significant.

3. **Time And Training**

   Students that have teachers with more training in a technology academically exceed students of teachers with minimal training in the same technology.

   The teacher had not been trained explicitly on the construction of the device and device-specific expertise was limited to the researcher. That is not to say that the teacher was not knowledgeable about the concepts and required skills outlined in the build guide. If integrating a technical project into the classroom, the teacher absolutely needs to have a reasonable understanding of the specific technology.

One significant barrier during the cooperative portion of the study was the effect on time from events outside control of the study. Factors such as the delay in the crabbing season and fishermen/researcher schedule limited how each participated. Fishermen work at odd hours of the day and in high-stress environments and may not be able to fully participate at certain times. The second limitation involved the compatibility of the technology used. Not all fishermen use modern technological amenities such as smart phones and may be diametrically opposed obtaining one for only the use in the study. It is important to consider and respect this when engaging in cooperative research. If relying on user devices, one should consider creating a custom interface or dedicated technology for sending and receiving data. In the case of this study, the transfer of data to a cheap tablet for data visualization may have been an option for fishermen to view data themselves without the need for researcher support.

4. **Perceived Value In The Technology**
   It is imperative that the application of the technology match that of the intended learning outcome. Is the technology a supplemental or centralized tool? Can you still teach a topic without the technology?

   From a scientist's perspective, there is apparent value in data. However, there was no emphasis on the value that the data could provide the students or fishermen. This should be considered when attempting to work with fishermen. Cooperation and collaboration may be possible among a wider audience if there is perceived value in the collected data.

5. **Evaluation Is The Weakest Element**
   An effective evaluation plan is needed to determine what changes need to be made when implementing a technology.

   Evaluation was certainly a weak point in this study. For the students there was no required homework or tests, which may have also contributed to the observed lack of motivation and progress. Although it was introduced as a single open-ended question in the post-assessment questionnaire, there was also no significant method for evaluating the effectiveness of the build guide and learning experience. A project like this would benefit from an evaluation regime that seeks to improve how the technology is used and what concepts can effectively be taught with its implementation.

6. **Access To The Correct Software And Hardware**
   Having the right amount of equipment per student has been found to improve student learning.

   Another contributing limitation of this study was the availability of software, hardware, and the environment which construction took place. It is easy to overlook these areas. Initially, the computers that the students utilized during the breadboarding and bench testing processes did not have the Arduino IDE and required administrator approval for installment. The lack proper soldering irons, drill bits, files, and metric hex wrenches resulted in the delay of some construction steps by a day or two. The workshop where construction was performed was small, cluttered, and arranged in a fashion that was not conducive to direct teaching. Desks faced in different directions and made it difficult to interact and explain a concept to all students at one time. Further showing the lack of motivation among students, the teacher would repeatedly ask them to clean up the workspace, but students only cleaned up once during the study period. Cleanliness and the proper tools at the start of the study would likely have made the process go more smoothly.

7. **Expertise Is Needed**

   Access to professionals with technological and pedagogical experience for a technology assists with integration.

   There also needs to be ample external expertise, whether it be through the teacher interacting with professionals, or students interacting with professionals. Scientific support was also restricted to the researcher. Had there been combined teaching support from oceanographers from the university or from the science teacher at the high school, the outcome of student perceived understanding of scientific concepts may have been different.

Chapter 4
Conclusion

4.1 Technology, Ocean Literacy, and Valuation

This research delved into the potential use of open source ocean technology as a vector for encouraging interest in and understanding of the marine environment. Many projects utilize technology to engage participants in science and research, but this is the first to utilize an open source CTD at its core. To assist in achieving this result, STEM students at Toledo High School were tasked with modifying and presenting their work on constructed CTDs and completed assessment questionnaires that focused on perceived interest and knowledge. Newport-based fishermen then utilized the student-constructed CTDs and participated in an exit interview which focused on fishermen interest in data and cooperative research participation. With some limitations, findings demonstrate that an experience centered about an open source oceanographic instrument may provide a pathway that elicits interest in and improves understanding of the marine environment. In turn, this presents opportunity for studies that involve low-cost operational oceanography, educational engagement for improved ocean literacy, and collaborative community interaction toward further relationship valuation. Findings also exposed lessons learned that could be utilized by developers, instructors, and researchers in the future that may facilitate the stable and successful application of an open source technology.

Earth's oceans are home to a number species, people, and enterprises. Across the globe, many have expressed concern that the general population lacks literacy and awareness in general ocean concepts, the availability of resources, the efforts taken to protect those resources, and shared use of the marine environment (Steel et al., 2005; Seys et al., 2008; Fletcher et al., 2009; Eddy, 2014). Awareness and understanding are key when communicating impacts, solutions, and making decisions that may change the status of ecosystem services and the use of resources. Many methods, such as radio advertisements, newspaper articles, and public forums have been successful in engaging the public, but those audiences are often limited (Steel et al., 2005). Connectivity established through the World Wide Web has made it possible for individuals to access information at the drop of a hat, offering another vector for increasing awareness and understanding. Much like learning in the classroom, there is no singular method that will engage the entire public and improve literacy. It is the availability of diverse learning avenues that ensures that public understanding of the ocean increases.

As shown by this research and corroborated by projects such as the MATE ROV and Coastal Drone Academy, working on a technology centered project provides students the opportunity to develop problem solving and technical skills, engage in applied science, improve understanding of basic ocean science concepts, work as a team to achieve a goal, and develop an understanding of business applications (Mann, 2011; Getter and Keene, 2017). These skills are transferable and critical for success in today's marine and STEM workforces (Zande, 2011; MATE Center, 2016). Per Zande (2011), the MATE Center suggests that a program designed to set up students for success in these workforces should:

1. Increase student awareness of marine STEM fields.
2. Emphasize ocean activities and careers.
3. Encourage the development of technical and SCANS skills.
4. Offer avenues for technical support.
5. Establish collaboration between students, universities, marine professionals, and future employers.

Following the MATE Center's suggestions, a technology-based STEM project is a reasonable pathway for furthering student ocean literacy if properly tuned and used in conjunction with other methods. As student literacy of the ocean improves, either in the classroom or through their marine-related careers, their valuation of it also increases (Guest et al., 2015). This in turn provides marine resource managers and policy-makers with knowledgeable and ocean-literate individuals that may be key in decision-making processes. A next step would be to determine the extent by which ocean literacy is improved and if a technology can be used to effectively introduce students to the management and ecological sides of the marine environment.

From an educational perspective, lack of preparation will ultimately reduce the effectiveness of lessons and the impact on student ocean literacy and valuation may be reduced. Although self-guided learning is useful in some ways, a group technical project requires an instructor that is not only present 100% of the time, but also has considerable knowledge regarding the technology that is being implemented. If a teacher places value on the technology and outcome, then students are more likely to do the same. If you are a researcher looking to test the effectiveness of a technology on ocean literacy and valuation in the teaching environment, then the teacher's presence in addition to your own is absolutely necessary. There should also be consideration for bringing in additional experts from fields related to the project. Some technologies may also have higher success rates than others, or may be found to be more engaging. For example, students may find that the construction and use of an Arduino-driven light sensor may be more interesting than the construction and use of a Secchi Disk. For group projects, peer-to-peer mentoring can also play a significant role in how the students learn and interact with one another. Expressed value in the ocean by a mentor may influence the mentee's sense of value as well. Tours, participation in conferences, and collaboration with researchers were also identified as possible supplemental methods for encourage the growth of student scientific knowledge, science identities, and SCANS skills. Future work should consider narrowing these fields to determine specific factors of tours, conferences, and collaboration that encourage growth. All of these factors should be considered when implementing a new ocean technology experience as a method for improving student ocean literacy.

The use of marine technology can make learning more engaging and interactive, assist in the development of relationships between community members, and allow decision-making through use of collected data. The effectiveness of a technology depends on the abilities of an instructor, the value assigned to the technology by those who implemented it and those who use it, how often it is used, and how many people utilize it (Valdez et al., 2000). To engage the public in ocean science and issues today, a technology needs to be simple to use, have defined and desirable outcomes, and provide users with the ability to reach a goal, whether it be from a personalized or stewardship perspective.

Learning how others use the ocean is also a method for improving ocean literacy, as it offers a different perspective for resource use and current issues. The transition from literacy to valuation can also be seen in Newport fishermen's desire to continue with participation in cooperative and collaborative work. Ocean valuation is much more than value assigned to resources, the environment, or places. There also exists value in relationships between stakeholders. The use of technology as a common ground has the potential to not only improve ocean literacy through data and interaction, but to also assist in the development of relationship valuation among ocean users. This consideration should first and foremost be taken by researchers looking to engage in cooperative fisheries research. Arguably, no form of data is more important than the human dimension that accompanies such ventures. Placing value over necessity in the relationship will likely encourage more participation in the future from both parties involved.

4.2 Considerations for Integration

For both the educational and cooperative portions of this project, the primary focus was on the construction, testing, and implementation of the device. There was very little reinforcement of science and literacy due to time. A hands-on, technology-based project looking to enhance ocean literacy and relationships, either in the classroom or as an engagement strategy, should incorporate the seven core principles and concepts outlined by the Ocean Literacy Initiative (Figure 1.1).

If integrating the CTD project into another high school setting, the researcher should use the Ocean Literacy Framework as a guide for introducing conceptual ocean and related technical subjects. Concepts from each principle could be introduced over one to two week periods while referencing the CTD as a central point. The following table shows what could be introduced based around the conceptual flow diagrams provided by the Ocean Literacy Initiative (Table 4.1).

Table 4.1: Ocean Literacy Framework Concept Introduction

Principle	**Concepts**
Principle #1	The ocean covers 70% of the Earth's surface. Students learn about salinity, thermohaline circulation, tides, and mixing. If near the coast, local examples and data can be used as a reference.
Principle #2	Ocean and oceanic life impact the Earth. Students learn about the roles of temperature, salinity, and elements in the various cycles of the ocean (Carbon, Phosphorous, etc). This could tie into local-marine based species as well as trans-oceanic migratory species.
Principle #3	The ocean influences weather and climate. Students can learn about consequences of global climate change through impacts to the physical and chemical makeup of the ocean (i.e. temperature and salinity). This can then be used as a transition to impacts on the fishing and aquaculture industries and introduce students to ocean users.
Principle #4	The ocean is a source of life. Students can be introduced to the effect that temperature and salinity have on oxygen content.
Principle #5	The ocean is diverse. Temperature and salinity can be connected to primary production, ecosystem diversity, and organism adaption to environmental factors for feeding and mating behaviors.
Principle #6	Humans and the ocean are connected. Temperature and salinity data use can be tied to industrial and recreational sectors. This can lead to discussions involving ocean use, people, and relationships to the ocean. Interactions with local industry may be beneficial.
Principle #7	The ocean is largely unexplored. This can lead to discussion of ocean observing systems, technology, low-cost sensor solutions, and the potential benefits of cooperative/collaborative research.

These principles do not have to be followed in order and can build off of concepts introduced in other coursework. However, it should be organized in a fashion that emphasizes the small-scale (temperature, salinity, local commercial fishing) and work its way toward big scale concepts (thermohaline circulation, relationships between different ocean users). This could provide students with a picture of what happens locally and globally. However, it is a lot of material to go through on top of teaching students how to construct a working prototype.

Although the CTD project involved students from multiple grade levels, similar projects may be better suited for more advanced groups. The project could be utilized as a capstone event for grade 12 students who already have a strong background in STEM or community college students who have an interest in science and technology. In the high school setting of this study, time was the most restrictive factor and resulted in a lack of ocean science topics covered in lessons. There are a few time-frames that could be tested to determine the best method for introducing both technological and ocean science topics effectively. In a semester setting, students could focus on the engineering and technology aspects and construct the devices in the first semester. Then during the second semester, students could learn more about the science side of the devices and utilized them to perform experiments. As many high schools utilize different teachers to go over such subjects, this could be done as combined effort between a career technical education teacher and a science teacher, similarly done by THS in the STEM program concept (Table 3.2). In the past, this collaboration between teachers appears to have had a positive outcome at Toledo High School, as the students would sometimes mention how scientific concepts they learned in the science class coordinated with items in the CTE classes. Another option is to have the construction of the device occur in a separate class, but in conjunction with an ocean science based class. Alternatively, the construction and implementation of a device could be done as a summer intensive course, where students spend multiple hours per day learning and building over the course of several weeks. This ensures that an instructor has ample time to cover more complex subjects. From this study, work on the CTD was generally only done while the researcher was present, resulting in about two hours of construction time per week. There needs to be constant supervision and interaction with the students by the instructor or researcher.

If attempting to implement a technical project into an educational setting, the researcher needs to ensure that the goals of the project are clearly outlined for both the instructor and students. If the goal of the project is to use the device to teach scientific subjects, then many of the more technical and engineering concepts can be removed from lessons and vice versa. This also needs to involve a verbal introduction to the goals, as well as a written form that can be referenced later. The researcher also needs to ensure that the instructor has had ample training to further understand how the technology works and is used.

Another focus of an experiential learning STEM project should be on the development of positive science identities. From some of the open-ended responses in the pre-assessment questionnaire, there were several students who did not know if anything about project interested them or simply offered a carefree response. Student engagement in science depends on how students view themselves and their inclination to participate. This is particularly important for female participants, as women are alienated in STEM subjects (Brickhouse et al., 2000; Carlone and Johnson, 2007). With the need for more individuals in operational, research, and technical careers in oceanography and science in general, positive engagement and the science identities of the students is key to filling those roles. One way to do this is to engage students and get them excited about science. However, if too complex or lacking in support, a project may reduce the students view of themselves and their engagement in science.

Fishermen already understand many of the principles and concepts outlined by the Ocean Literacy Initiative. From observations within this research, in conjunction with other findings, some fishermen may want to transition from a cooperative role in research to a more collaborative one. This provides an opportunity to reinforce Principle #6 in terms of ocean users outside of commercial fishing. If engaging fishermen in a cooperative research project that involves prototype development, a more collaborative approach should be taken if the intention is for the prototype to be utilized by fishermen. Apart from the use of suggestions for the prototype, the researcher should consider including fishermen input in every aspect of the study design process.

4.3 Future Cooperative and Collaborative Projects

The lens by which fishermen view the ocean is significantly different from that of researchers and managers. With that lens comes a substantial amount of LEK that can be extremely useful in the future development of operational oceanographic projects and fisheries-related research. As demonstrated, fishermen are interested in collaborative fisheries work and make fisheries-relevant observations that can be turned into questions that can be tested. A collaborative effort could consist of an amalgamation of fishermen questions and researcher methods. Fishermen observations provide insight into issues that impact their livelihoods, while researchers provide a deep understanding of processes and technical knowledge that can be used to derive answers to questions.

There are a variety of environmental factors that impact crab location and fishermen are interested in learning more about them. Although data from this project was limited and there was no discernible trend in catch size and water quality, there is still potential for future research that both fishermen and scientists may be interested in. For example, many fishermen have specific areas where they like to crab. As crab pots are considered to be reasonable platforms of opportunity, data collected could help determine if crab movement and residence is a function of bathymetric features, environmental conditions, or both (Childress, 2010). Scientists could take on the role of data analysis and instrument upkeep, while fishermen take on the role of data/specimen collection and at-sea observations. Data could benefit fishermen and assist them in making decisions for fishing, while scientists could benefit from understanding more about crab habitat. Funding, the availability of training, and the usefulness of seminars should be considered when attempting to implement an ICT that facilitates data collection and communication between parties. (Benard and Dulle, 2017).

Observed from this research there appears to be relationship between age and willingness to participate in cooperative research. As graying of the fleet persists and members of the digital generation establish themselves in the Newport fishing community, the use of technological gear studies may be one method for establishing communication and trust. Previous work has found that fishermen that use one gear type tend to only interact with other fishermen that use the same gear type, creating divides within the fishing community (Crona and Bodin, 2006). Knowledge, previous experience, and expressing interest in a gear type may assist future researchers looking to engage in cooperative science. Communication and trust with future generations is essential to continued cooperative and collaborative research in any area. As current studies involving graying of the fleet in Newport, Oregon reveal more information about the younger fishing generation, tactics for engagement could be applied to a wider geographic area.

4.3.1 A Multi-Partnership Project in Newport, OR

Members of a coastal community have one thing in common, and that is the place they reside. Despite this, members may be at odds with one another over a particular issue, or simply do not enter circumstances that allow them to interact. The research outlined in this thesis could have brought together three groups in the Newport community, but due to timing and conflicts such events did not occur. One study involving community interaction centered about a photograph service found that communication and understanding is enhanced when each group shares a common ground (Wang et al., 2004). The leap here is that an ocean technology centered project could bring together different members of a coastal community and offer a platform for which the transfer of knowledge could take place.

Since the removal of the Yaquina LOBO in 2013, there has been no publicly available multi-parameter water sampling platform in Yaquina Bay. Reigniting Yaquina LOBO offers opportunity to bring together students from local schools, commercial fishermen on the north side of Yaquina Bay, and scientific researchers on the south side. All groups could play a role in the project, from the turning of wrenches to the use of data for evidence-based decision-making.

Table 4.2: Roles in Reigniting LOBO

Group	Role
Students	Maintain the mooring. Utilize data for learning activities involving estuarine oceanography, data presentation, and analysis.
Fishermen	Assist with deployment and recovery of mooring, provide power for instruments. Utilize data for personal use and decisions that occur in the bay.
Scientists	With assistance from students, format data for fishermen use. Assist industry with deployment and recovery of the mooring. Utilize data for research.

From a knowledge perspective, students can gain an enhanced understanding of biological knowledge through fishermen local ecological knowledge (Kimmerer, 2002). The interaction between students and scientists could also serve to enhance learning by providing access to expertise for a field. From a communication perspective, interactions that occur between the scientists and fishermen may be additive to the cooperative and collaborative efforts that are already happening in the bay. Processors and aquaculture along the bay front and river banks could also utilize the information from a LOBO mooring. There are obvious weaknesses in this concept, such as funding and initiation, but it does outline some of the possibilities of utilizing a piece of technology as a community meeting point.

4.4 Future Technical and Educational Projects

4.4.1 Open Source Instrumentation and Platforms

The CTD developed in this study, while a step toward the simplification of open source environmental sensing for all, still leaves much to be desired and can be improved upon greatly. A new version of the device will be constructed in the near future and will attempt to include more accurate sensors, an improved pressure case design, and functions that will remove skepticism for speed, accuracy, and long-term stability. Additionally, a cost/benefit analysis will be performed to determine if cost can be reduced to make the device more attractive for end users such as educators and citizen scientists. This new version will likely utilize a Raspberry Pi and the Blue Robotics 4-inch watertight pressure case. Newer boards have on-board Bluetooth and

WiFi capabilities, and the 4-inch pressure case allows for larger batteries, increasing the amount of time an instrument can be deployed. While Arduino microcontrollers and the Arduino IDE are easy to use and simplify environmental sensing, the addition of Python on the Raspberry Pi make expansion potentially limitless. In constructing a device for environmental monitoring, the following should be considered:

1. **Larger Battery Capacity**
   More battery provides the opportunity to collect data for longer. It is difficult to find LiPo batteries that have large amp-hours and still maintain a small form factor. Using the current configuration of the CTDizzle, a device capable of sampling for 30 days at 1Hz will need a 3.7v LiPo battery pack with at least a 25,000 mAh capacity.

2. **Size**
   A smaller CTD is less obtrusive, while a larger CTD offers larger battery capacity. The simplicity of a device also plays a role in whether or not fishermen will use it in gear studies.

3. **Voltage Isolation**
   Although mass-produced and quality checked, Arduinos and other microcontrollers can generate electrical noise that impacts sensor readings.

4. **Cost and Application**
   Deployment location can be a factor in costs. If only deploying a CTD in a bay, PVC can be used as the housing material making for a cheaper CTD.

5. **Accuracy**
   If you only need to determine the location of the thermocline, then a fast response sensor but less accurate temperature sensor can be used. However, if you need to determine temperature change to an appropriate degree, then a fast and higher accuracy probe should be desired.

6. **Recurrent Costs**
   O-rings should be cleaned, greased, and replaced often. Batteries lose the ability to charge after several hundred cycles. Calibration should be performed annually using standards.

7. **Long-Term Stability**
   Drift does not become apparent in most of the sensors utilized by the CTDizzle until 2-3 years after the manufacture date.

8. **Environmental Conditions**
   Longer deployments lead to the risk of galvanic corrosion, so cathodic protection should be utilized. Biofouling can also impact data quality.

Many individuals and groups are taking on the role of developing open source, modular, and low-cost environmental equipment. The OpenCTD foundation established by Oceanography For Everyone has resulted in a variety of CTD builds that have been utilized for a number of purposes. One individual has developed a CTD based around a Raspberry Pi Zero that also includes a camera and lights for monitoring species in benthic environments (Haan, 2017).

Another individual has taken the CTDizzle build and modified it for use on a ROV and for monitoring water quality in wells (Teague, 2017).

The Cave Pearl Project developed an Arduino-based data logger that can survive relatively harsh environments and can have a number of sensors integrated into the package (Beddows and Mallon, 2018). There exists a number of opportunities for individuals or groups to kludge together already made components or develop their own so that environmental sensing of multiple parameters is more affordable and widespread. Although these systems often lack the accuracy and robustness of commercially produced versions, there is still value in providing methods for early-career researchers, educators, and citizen scientists to sense the environment at a lower cost. The addition of more environmental information allows us to hone in on areas of interest and make potential decisions.

Toward the beginning of 2017, a guide for building an open source underwater glider (OSUG) was released on hackaday.io (Williams, 2017). Lagrangian assets, such as gliders and drifters, are used widely in operational oceanographic initiatives and provide opportunity to sample in less accessible locations for extended periods of time. Much like the construction of an ROV, the building of an OSUG would provide students with another in-depth look at the marine technology sector, but also enhance their understanding of the ocean.

Although the CTD data collected during this study may be questionable, it is clear from this study and the examples provided that it is possible for someone to construct their own environmental sensor and learn a tremendous amount in the process. With the recent explosion in the availability of microcontrollers, computational platforms, and sensors, environmental sensing is becoming more accessible and low-cost for everyone. Although the CTD provides fundamental physical information about our oceans, there are a variety of other issues that researchers, students, and the public are interested in, such as ocean acidification, hypoxia, and harmful algal blooms. The manufacturers that produced parts utilized in the CTDizzle also sell microcontroller-compatible pH, pCO2, dissolved oxygen, and color sensors, among many other types. The modular nature open source devices makes it possible for someone to develop their own sensor that can be used to monitor such issues and spark efforts that utilize commercial instruments.

4.4.2 Open Source Observing Distributed Active Archive Center

Distributed Active Archive Centers (DAACs) are centralized conglomerates of data sources. For example, NANOOS is the ocean, meteorological, and stream data DAAC for the northwest US and combines data sources from universities and governmental entities. The Integrated Ocean Observing System (IOOS) further combines all regional systems in one place. To ensure that data is valid, the IOOS utilizes the Quality Assurance/Quality Control of Real Time Oceanographic Data (QARTOD) plan (IOOS, 2017). As they currently sit, data produced from open source oceanographic instruments like the OpenCTD or Arduino-based Sonde will likely not pass the stringent validation requirements established by QARTOD. However, that does not prevent the data from being of value to users. Establishing a centralized data repository for user-built open source instruments and platforms gives others the opportunity to share data and improve the technology. The low-cost nature of open source technology leads to the possibility of a wider range of continuous coastal coverage compared to what current systems provide. However, expense and communication protocols likely limit the geographic extent of such a DAAC to the nearshore. With this in mind, two of a perceivably infinite number of possibilities are described below.

Educational Engagement Through Data Distribution

From an education perspective, the establishment of an open source observing DAAC could allow multiple schools collaborate and monitor the same data set and conveniently share that information. As an example, students from high schools in Brookings, Newport, and Astoria, OR could monitor bay bottom salinity at the commercial docks for a class project. Using a server and a modified CTDizzle, students can stream and make data available in real-time. A DAAC would then combine all three sources of bottom salinity and make the data available in a tabular or visual format. In turn, each student could utilize bottom salinity data from the other bays and perform analyses on the difference in salinity between sites, the effect of tides on bottom salinity, or the timing of tidal propagation along the Oregon coast. As another example, all of the schools along the Oregon coast could walk down to the beach during Earth day, and in a synchronous effort measure the temperature and salinity of the water. That information could then be uploaded to a DAAC and visualized as a layer on a map. Opportunities such as this can promote the ownership of data, enhance student understanding of the environment, and introduce students to data quality, analysis, and processing methods.

Industry Engagement Through Data Distribution

From an industry perspective, fishermen are curious about the environmental conditions that surround their professional activities and sometimes use environmental data in decision-making. For example, a fishermen coming into port may be curious about the surface salinity of the bay, as low salinity water may be detrimental to the catch they have in their tanks. Using open source technology, a low-cost system could be established on ships that automatically logs surface salinity with geographic coordinates and transmits that information wirelessly once in range to a master device. To remove concern for tracking issues, the system could be set up to only log data inside a certain watch circle range. A DAAC or data portal then pulls that information and displays it on a map that fishermen have access to. If the surface salinity is too low on the map, then they know not to pump water from the surface layer.

4.5 Future of Environmental Monitoring

Technology has changed the way we live, interact with one another, and how we make decisions involving the environment and the resources it provides. Engaging students in STEM leads to the possibility of future innovation in environmental monitoring technology, and the incorporation of fishermen leads to new and exciting methods for collecting key environmental data utilized in decision-making. The development of the CTDizzle and open source projects reviewed represents a movement toward cost-effective environmental monitoring. As the human population continues to influence the marine environment, these cost-effective methods will play a role in addressing the need for data.

The CTDizzle framework will be a continually evolving system. To access the most recent version of the build guide, code, and scripts, go to:

https://github.com/CTDizzle/CTDizzle

Nomenclature

AUV	Autonomous Underwater Vehicle
CR	Cooperative Research
CFR	Cooperative Fisheries Research
CTD	Conductivity, Temperature, Depth
CTE	Career Technical Education
DAAC	Distributed Active Archive Center
EC	Electrical Conductivity
EOS80	1980 Equation of State for Seawater
FAA	Federal Aviation Administration
F/V	Fishing Vessel
ICT	Information and Communication Technologies
IDE	Integrated Development Environment
IOOS	Integrated Ocean Observing System
IRB	Institutional Review Board
JRCGC	Juvenile Rockfish, Cabezon, and Greenling Collaborative Fisheries Research
LEK	Local Ecological Knowledge
LiPo	Lithium Polymer
LOBO	Land Ocean Biogeochemical Observatory
MATE	Marine Advanced Technology Education
NANOOS	Northwest Association of Networked Ocean Observing Systems
NASA	National Aeronautics and Space Administration
NGSS	Next Generation Science Standards
NH	Newport Hydrographic
NOAA	National Oceanic and Atmospheric Administration
NSES	National Science Education Standards
NSF	National Science Foundation
OOI	Ocean Observatories Initiative
OrFIOOR	Oregon Fishermen in Ocean Observing Research
OSG	Oregon Sea Grant
OSM	Ocean Sciences Meeting
OSU	Oregon State University
OSUG	Open Source Underwater Glider
PCB	Printed Circuit Board
PSS-78	1978 Practical Salinity Scale
PSU	Practical Salinity Units
PVC	Polyvinyl Chloride
R/V	Research Vessel
ROV	Remote Operated Vehicle
RTC	Real-Time Clock
SBE	Seabird Electronics
SCANS	Secretary's Commission on Achieving Necessary Skills
SoTC	State of the Coast
STEM	Science, Technology, Engineering, Mathematics
THS	Toledo High School
UNOLS	University-National Oceanographic Laboratory System
US	United States
USD	United States Dollar
USGS	United States Geological Survey
YSI	Yellow Springs Instrument

°C	Degrees Celsius
°F	Degrees Fahrenheit
Hz	Hertz
m	Meters
mAh	Milliampere Hours
mbar	Millibars
ppm	Parts Per Million
uS/cm	MicroSiemens Per Centimeter

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Appendix A
Supplemental Materials

Figure A.1: System Diagram

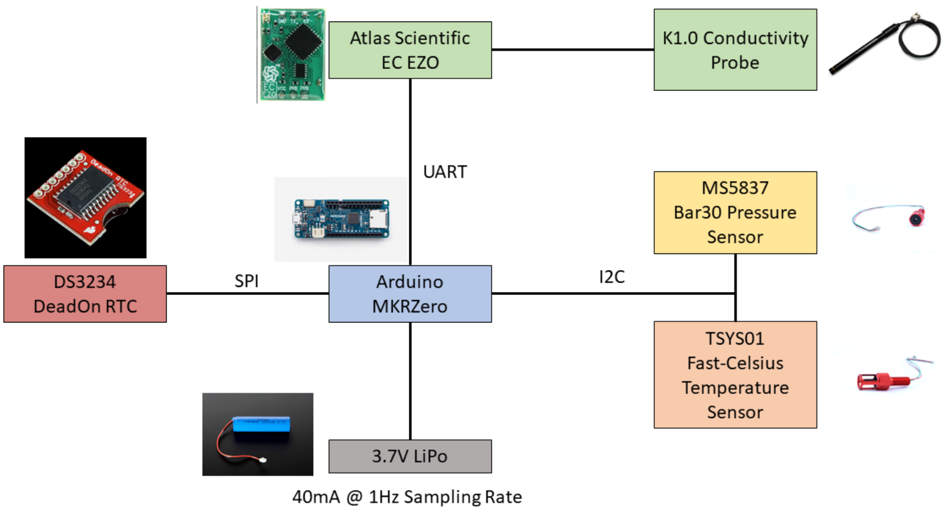
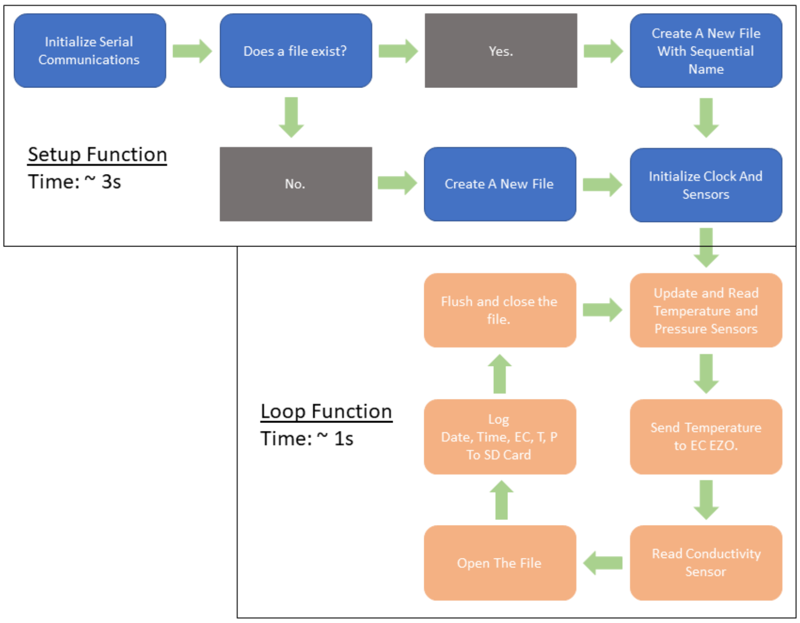


Figure A.2: Operating Pseudo Code



Archimedes' Principle

Purpose

The purpose of this exercise is to introduce you to Archimedes' Principle and how to mathematically determine if our CTD will float or sink before we put it in the water.

Introduction

Archimedes' was asked by Hiero II of Syracuse to determine if a royal crown was fake. Hiero did not believe that the crown was made of pure gold, but also included some silver. He tasked Archimedes with determining the nature of the crown by a nondestructive means. By placing the crown in a water bath, Archimedes was able to see how much water was displaced by the crown vs a matching mass of pure gold. Using some basic math and his brain, he was able to determine the chemical makeup of the crown.

Spoiler Alert: It didn't end well for the guy who made the crown.

Let's Do Some Math

Using some of the math behind Archimedes' Principle, we can determine if our CTD will float or if it will sink.

First, we must determine the force of gravity on our CTD.

$$F_g = M * g = \rho_{CTD} * A * H * g$$

where M = mass of our CTD, g = gravity, ρ_{CTD} = density of CTD, A = area of endcap , H = height of CTD

Now we must calculate the buoyant force on the CTD. **The buoyant force is only dependent on the density of the surrounding fluid, the volume of the CTD, and gravity.**

$$F_b = \rho_{water} * A * H * g$$

We can determine the sign of the force on our CTD by subtracting the force of gravity from our buoyant force.

$$F_{CTD} = F_b - F_g$$

If F_CTD is negative, then the force of gravity is greater than the buoyant force, so the CTD will sink.

If F_CTD is positive, then the force of gravity is less than the buoyant force, so the CTD will float.

Archimedes' Principle

Measure the mass and volume of the CTD (assume it is a true cylinder, ignoring the sensors). Assume a seawater density of 1035 kg/m3 and a gravity value of 9.81 m/s2. Use the above equations to calculate the force on the CTD.

Mathematically, will the CTD float or sink? Does this match our observations from when we put it in the PVC pipe tank?

If the CTD floats, calculate how much the CTD needs to weigh in order for it be become neutrally buoyant (set Fb=mass*gravity and solve for mass).

Takeaway

The force of buoyancy on an object is only dependent on the volume of the object, gravity, and the density of the surrounding fluid. The force of gravity is dependent on the mass of the object and gravity. If the force of gravity is greater than the force of buoyancy, the object will sink (negatively buoyant). If the force of buoyancy is greater than the force of gravity, the object will float (positively buoyant. If the buoyancy equals gravity, the object will stay put and neither sinks or floats (neutrally buoyant).

Hydrostatic Pressure

Purpose

The purpose of this exercise is to introduce you to pressure in the ocean and to give you the tools necessary to quality check the pressure sensor on the CTD. You will mathematically calculate the pressure at the bottom of a tank and then compare that value to what the CTD reports.

Introduction

Pressure can be thought of as a force on an area. Hydrostatic pressure is basically just that, but defined to be the measure of the force a column of fluid exerts on an area (hydrostatic meaning a stationary column of fluid over the object).

Equation 1

$P = \frac{F}{A}$	where, P = pressure F = force A = area
$F = m \times a$	m = mass a = acceleration

Let's say I place a brick on a piece of paper, which gives me some value of pressure. If I add another brick of the same weight, I am effectively doubling the original force on the piece of paper, so the pressure will also double.

The standard units for pressure are N/m^2, but Equation 2 will give you the pressure in pascals (because scientists are not original and like to name things after other scientists). The pascal is a weird unit, so oceanographers like make things even more confusing and translate it to decibars or millibars. For the rest of this exercise, we will use millibars, as that is what our CTDs report for the units of pressure by default. For reference, **1 millibar = 100 Pascals**, we will use this conversion later.

In the ocean, there is a clear relationship between the height of water above an object and the pressure that it experiences. The following equation is known as the hydrostatic equation and helps us explain that relationship.

Equation 2

$p = \rho g z$	where, p = pressure (in pascals) ρ = density of fluid (in kg/m^3) g = gravity (in m/s^2) z = height of fluid (in m)

Hydrostatic Pressure

Example

If we put a penny at the bottom of a tank filled with water we can calculate the pressure the penny experiences by using Equation 2. Let's assume that the water in the tank is 100 meters in height, that the water has a density of 1035 kg/m^3, and that gravity is 9.81 m/s^2.

$$p = 1035\ \frac{kg}{m^3} \times 9.81\frac{m}{s^2} \times 100m = 1,015,335\ pascals$$

$$p = 1,015,335\ pascals \times \frac{1\ millibar}{100\ pascals}$$

$$p = 10,153\ millibar$$

You can see here that the number of millibars is almost equal to how tall our tank is if you multiply the tank height by 100. This is because pressure linearly increases as you go down in depth. **A good rule of thumb is that for every meter you go down, your pressure increases by one hundred millibars (or one decibar).**

You may be wondering why we used 1035 kg/m^3 for the density. That is the average density of seawater. If we had freshwater in our tank, we would have used 1000 kg/m^3.

Calculation

Using the equations and values above, you should be able to calculate the pressure at the bottom of the tank we will build. All you need is the height of the water in the tank. Assume we are using freshwater (density of 1000 kg/m^3) and the average value of gravity (9.81 m/s^2).

Height of Water in Tank (m) =

Mathematically calculate the pressure at the bottom of the tank using Equation 2.
What is the pressure (in millibars)?

Hydrostatic Pressure

Observations

Next, take a completed CTD, attach a rope and some weight to it, turn it on, and lower it slowly to the bottom of the tank. Leave it at the bottom for about 30 seconds. Recover the CTD and pull the SD card to view the data in Microsoft Excel.

You should see the pressure in the fifth column. Scroll down until you find the point where the pressure levels out at a maximum (pick a pressure from a time point where you left the CTD at the bottom for 30 seconds.

What is this pressure reading (in millibars)?

You may notice that the value the CTD recorded seems to be about 1000 millibars greater than what we calculated using Equation 2. This is because the CTD is also measuring the pressure added by the atmosphere above the tank, or the absolute pressure. In our by-hand calculation, we are excluding this value, which gives us a relative pressure. To make our CTD pressures only relative to the water level, subtract the very first value from your greatest pressure value.

What is your relative pressure reading (in millibars)?

How does the relative pressure value compare to what you calculated in Equation 2?

Quality Check

If the CTD value and the calculated value are within 20 millibars of each other, then the pressure sensor is reasonably accurate. If your values are drastically different, then there is likely a defect with the sensor. There isn't much we can do to fix that at this point.

Takeaway

The main thing I want you to recognize is that pressure increases linearly as you increase your depth. While the density of the fluid and gravity have some impact on the pressure, the thing to note is that the pressure an object experiences in the ocean is dependent on the height of the water above it.

Salinity

Purpose

The purpose of this exercise is to introduce you to salinity, how it is calculated and measured, and what it tells us about our oceans. We will do a quick unit analysis and then learn how conductivity, temperature, and pressure are used to calculate salinity.

Introduction

Salinity is an odd measurement. It took scientists many years to decide on the units (which really all represent the same thing). For a while, people used parts per thousand (‰), then in 1978 they switched to practical salinity units (PSU), and then in 2010 they switched to absolute salinity. In most scientific papers you will see the use of PSU, as most oceanographers are old and don't like change.

Now you are probably thinking, "Ian you big dummy, our CTD doesn't measure salinity."

That is correct. Salinity is technically a value that is calculated from a combination of conductivity, temperature, and pressure. We measure conductivity because that gives us an idea of how many salt ions are in the water, and the temperature and pressure at which our measurement is taken impacts the conductivity of the water.

What is Salinity?

Really, salinity is just a measure of how many grams of salt there are in a kilogram of seawater.

$$\frac{\#\ kilograms\ of\ salt}{1\ kilogram\ of\ water}$$

The transition from PSU to g/kg is pretty straight forward. Say I have 1kg of seawater, and I want to find out how many grams of salt there are in it. 1 PSU = 1 gram salt per kilogram seawater. Let's use a sample that has a salinity of 35 PSU. Therefore,

$$35\ PSU\ =\ \frac{35g\ salt}{1\ kg\ water}$$

It would be difficult to take a kilogram of seawater, boil it, and then weigh the amount of leftover salt, so scientists use a set of equations to calculate salinity. Three environmental values are needed to calculate salinity. Conductivity, temperature, and pressure (or exactly what our open source CTD measures). After we have all three values, the information is entered into some really complex equations. We won't go into that any more, but if you are interested in learning more, just Google "PSS-78" or "Computational Algorithms of Seawater".

The Earth's oceans, on average, have a salinity of 35 PSU. This value changes depending on location, atmospheric conditions, depth, and a whole bunch of other factors. Generally, ocean

Salinity

salinity at the surface is less where freshwater is input from rivers or by rain. Salinity at the surface is also generally greater where evaporation is prevalent and where temperatures are cold enough to form sea ice (like the arctic). How do you think salinity in Yaquina Bay changes with tides?

Exercise

1. Go to http://yaquina.loboviz.com/loboviz.shtml
2. For the X-Variable, select date.
3. For the Y-Variable, select only salinity.
4. For the Date Range, select all dates.
5. Select “Plot the data”.
6. Notice how salinity changes with time. Why?

Hint: Look at the historical daily discharge for the Yaquina River at Chitwood.
https://waterdata.usgs.gov/nwis/dv?cb_00060=on&format=gif_default&site_no=14306030&referred_module=sw&period=&begin_date=1985-12-29&end_date=1988-12-29

How Much Salt Do We Need to Make Our Tank Salty?

Now let’s try to calculate how much salt we would need to make our PVC pipe tank have a salinity of 35 PSU.

For our tank, we first need to calculate the internal volume of the pipe to get how much water is needed to fill it. Then we can use that number to estimate how much salt we need to add to get 35 PSU.

$$Cylinder\ Volume\ (m^3)\ = \pi r^2 h$$

where r = internal radius of tank (m), h = height of tank (m). Measure in meters to make the calculation easier. Assume we are using 4” Schedule 40 PVC that is 7 meters in length.

Once we have the volume, use the density of freshwater to determine the mass of the water.

$$Cylinder\ Volume\ *\ 1000\ \frac{kg}{m^3} = Mass\ of\ Water\ (kg)$$

Now that we know the mass of water, we can solve for how many grams of salt we will need to add to the tank to make it equivalent to 35 PSU. Recall that salinity is just grams of salt per kilogram of water.

$$\frac{\#\ grams\ Salt}{Mass\ of\ Water\ (kg)}\ = 35\ PSU$$

Salinity

How much salt do we need to add to our tank to make it have a salinity of 35 PSU?

Takeaway

The key concept here is that salinity is a measure of how many salt ions exist. It is difficult to measure this directly, so scientists use a CTD to calculate the salinity with a high degree of accuracy. The value of salinity is mostly impacted by how many salt ions exists and the temperature of the water. Salinity also varies in the ocean due to freshwater input.

Density

Purpose
The purpose of this exercise is to introduce you to density, how it is calculated, and what it tells us about our oceans.

Introduction
Density is basically how much stuff there is in a certain volume. Commonly, the units of seawater density are expressed in kilograms per cubic meter.

$$\frac{\textit{\# kilograms of stuff}}{m^3}$$

It is difficult to measure this with a scale. One cubic meter of seawater weighs over 1000 kg! So scientists use a string of equations that use salinity, temperature, and pressure to come up with density. These equations are a lot different than the ones used to calculate salinity and are much more complex. We won't dive into these equations, but it is important to recognize that there are a few factors that influence density.

Factors Influencing Density
For reference, pure water (as in only H2O, nothing else), has a density of 1000 kg/m3. Ocean water has an average density of 1035 kg/m3 (due to the presence of salt ions and other stuff).

If we increase the temperature, molecules in the water get really excited and start moving around a lot more, so the water expands. If we have one cubic meter of seawater at one temperature and then heat it up, it expands. Nothing was added to the seawater so the mass (# of kilograms) remains the same. The only things that changes is the amount of space that the seawater takes up. Therefore our density decreases. (Same amount of stuff but in a larger volume).

If we increase the salinity of our 1 cubic meter of seawater, we are effectively increasing the mass but keeping the volume the same. Therefore as salinity increases, density increases. (More stuff in the same amount of volume).

If we increase the pressure on our 1 cubic meter of seawater, we are effectively compressing the water. Our mass stays the same, but our volume decreases. Therefore our density increases. (Same amount of stuff but in a smaller volume).

If	**Then**
Temperature ↑	Density ↓
Salinity ↑	Density ↑
Pressure ↑	Density ↑

Density

Takeaway

The density of our oceans varies in time and location. It is highly dependent on salinity, temperature, and the pressure. Salinity and temperature play a larger role in changing density than pressure. Differences in density sometimes cause the ocean to move and circulate (think about what happens if you put more dense water over less dense water).

Temperature

Purpose
The purpose of this exercise is to introduce you to temperature, how it is measured, and why we care how hot or cold the ocean is.

Introduction
Temperature is the measure of the average kinetic (or thermal) energy of the particles in a substance. Substances with more energy have higher temperatures.

If two objects, one of high temperature and one of the low temperature, contact each other, some energy is transferred to the object with the lower temperature. This energy transfer is called heat.

How Does the CTD Measure Temperature?
Our CTDs use a small temperature sensing chip called the TSYS01. The chip uses a thermistor to obtain a resistance value, then converts that value to an electrical signal, which our microcontroller (the MKRZero) converts to a human-readable temperature value.

As temperature changes in the environment, the resistance given by the thermistor changes. This change is not exactly linear, but generally in the ocean (above 0 degrees) the resistance of seawater increases with decreasing temperature. This relationship is also seen by our conductivity sensor. Conductivity, which is simply the inverse of resistance, increases with increasing temperature.

If the TSYS01 is hooked up to a microcontroller (MKRZero), the two work in conjunction to create human-readable values. By default, the TSYS01 outputs temperature in Celsius. For most scientific purposes, this is acceptable. However, if you want to convert to Fahrenheit, use the following equation.

$$\# \, degF = \# \, degC * \frac{9}{5} + 32$$

Exercise
1. Go to http://yaquina.loboviz.com/loboviz.shtml
2. For the X-Variable, select date.
3. For the Y-Variable, select only temperature.
4. For the Date Range, select “all dates”.
5. Select “Plot the data”.
6. From the graph, estimate the highest and lowest temperatures to the nearest tenth of a degree. If you want, pinpoint the date of those values and replot the data for a more accurate value.
7. Convert these temperatures to Fahrenheit.
8. Also make a note of how temperature changes with time. Is it warmer or colder during the day? What about during the summer vs winter? What about in between tides?

Temperature

Bonus
Scientists sometimes like to use Kelvin for temperature (mostly for atmospheric stuff). When you hear things like “absolute zero”, that is in reference to 0 Kelvin. Look up how to convert Celsius to Kelvin. Repeat part 7 but with Kelvin instead.

If interested, here is more info on LOBOVIZ: http://yaquina.loboviz.com/
The website also links to wikipedia pages that offer a lot more information.

Why should we care how hot or cold the ocean is?
There are a variety of reasons why temperature is important to measure. To name them all would take ages. Here are a couple key topics.

1. Temperature plays a vital role in how our oceans move. Far below the surface, away from the influences of the wind, density differences cause deep water to move from one location on Earth to the next. These density differences are primarily driven by differences in temperature. For more information, search for “Thermohaline Circulation”.

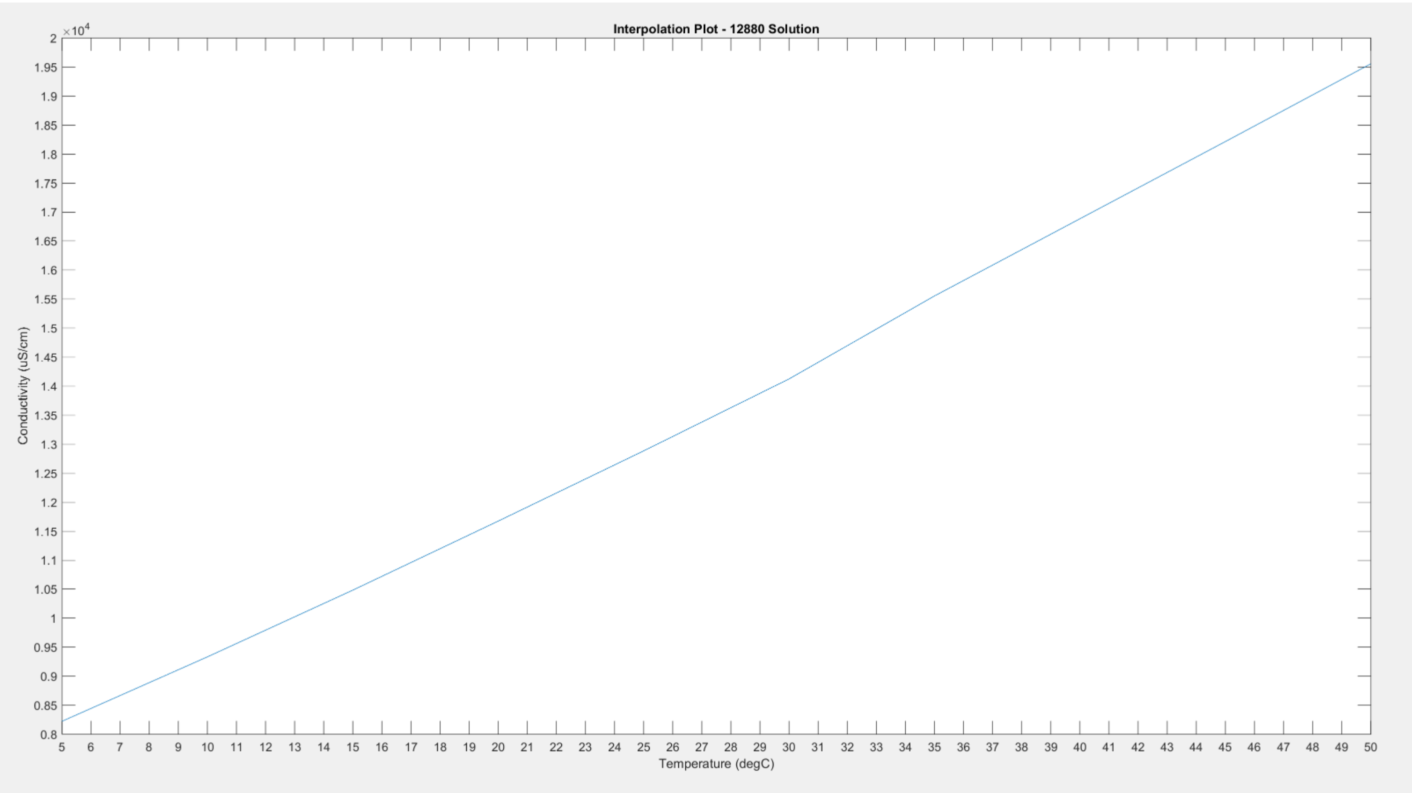
2. Temperature impacts how much gas water can hold. Warmer water holds less gas than cold water. This means that warmer ocean waters hold less carbon dioxide, and as the amount of carbon dioxide in the atmosphere continues to increase, the amount of carbon dioxide our oceans can physically absorb decreases, further contributing to temperature rise.

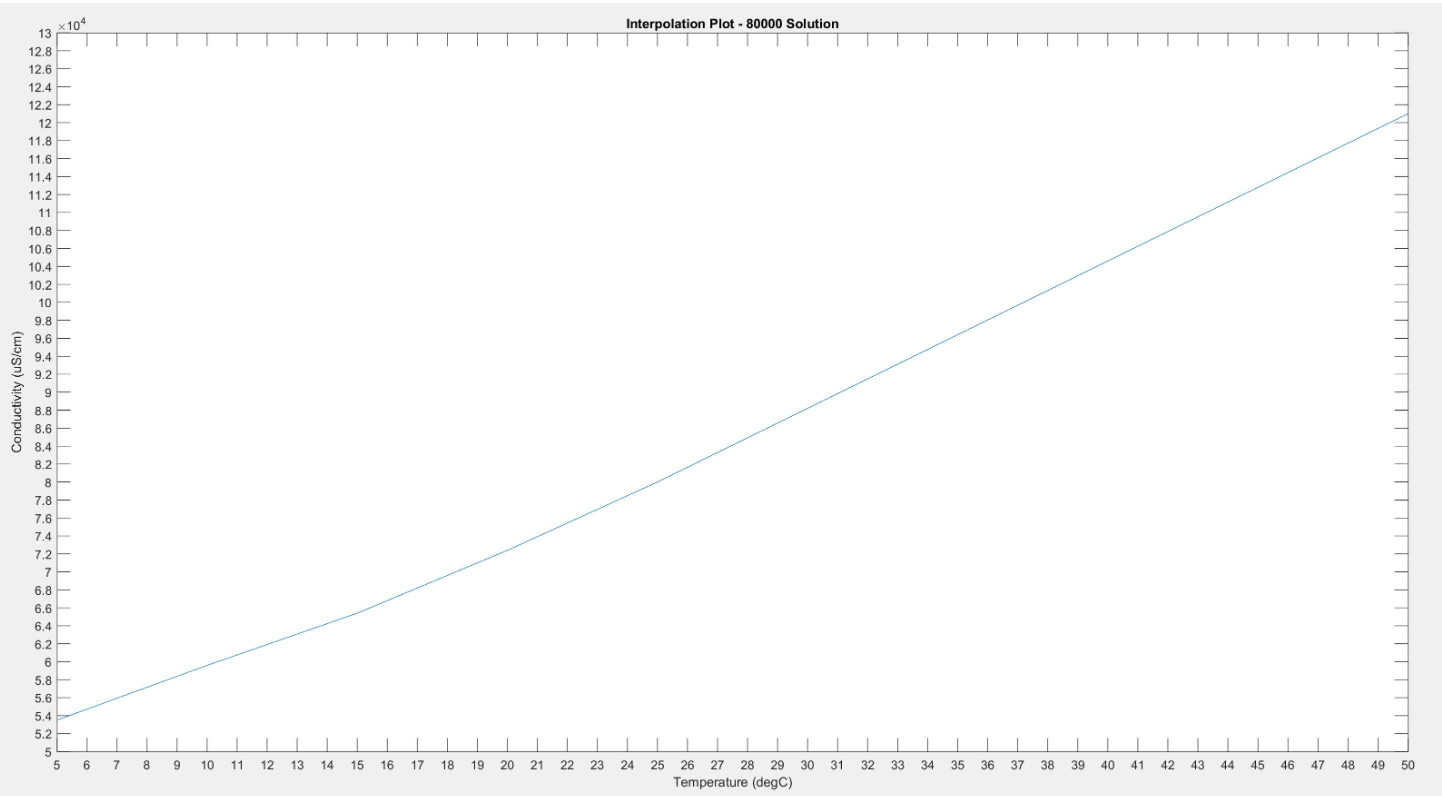
3. Temperature also impacts the biological components of the ocean. Crabs and fish prefer to hangout in certain temperatures. Some algae won’t begin to bloom until a certain temperature is reached.

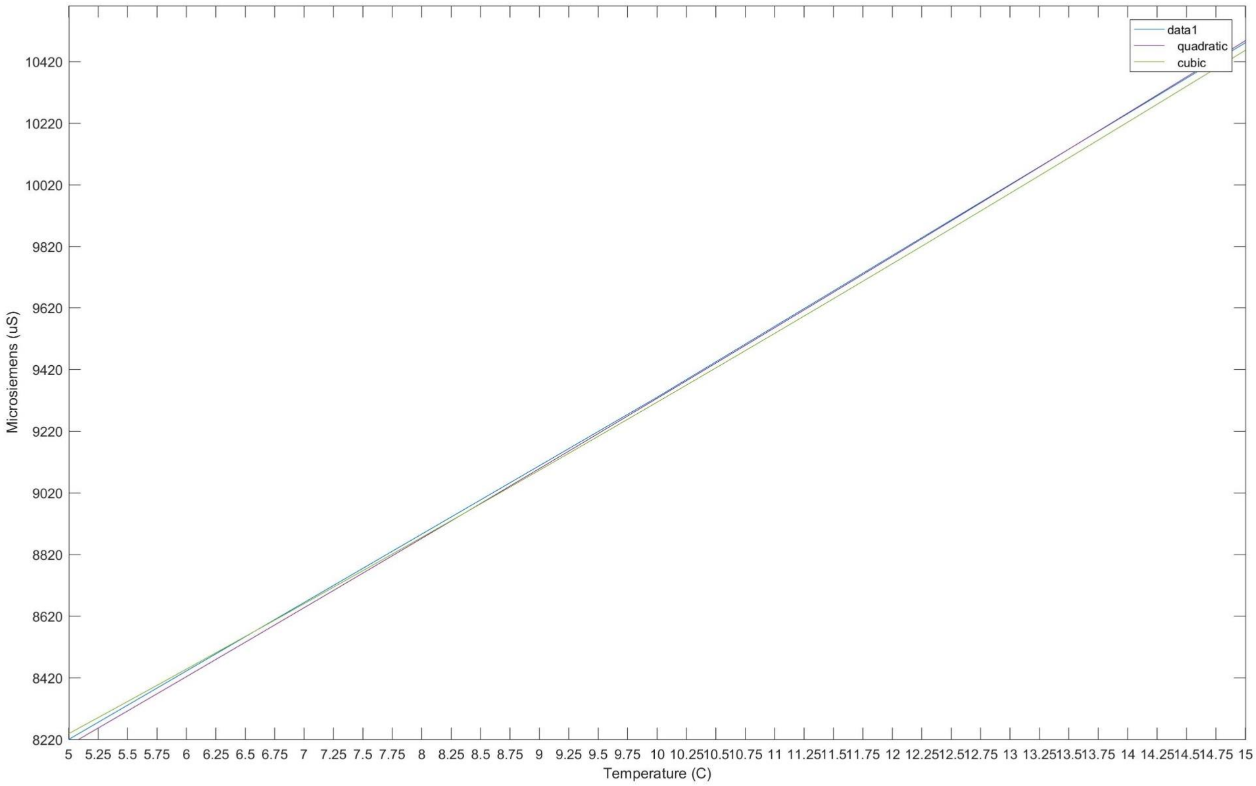
Atlas-Scientific EC EZO Calibration Procedure				
Calibration Performed By:		Probe Serial Number:		Procedure Drafted By: *Ian Black (2017-09-05)*
Calibration Date:		EC EZO Name:		Solution Temperature:
Step	**Procedure**	**Check**	**Results**	**Notes**
1.1	Turn the external switch to off. Open the unit by removing the switch/pressure end cap.			
1.2	Disconnect the battery. Remove the microSD card.			
2	Connect the MKRZero to the computer via microUSB cable.			
3.1	Open the Arduino IDE.			
3.2	Navigate to Tools > Board. Ensure MKRZero is selected.			
3.3	Navigate to Tools > Port. Select available com port. Usually, MKRZero will be in parentheses next to the com port number.			
3.4	Navigate to File > Sketchbook > MKRZero_EC_Cal			
3.5	Navigate to Sketch > Upload. (Ctrl+U)			
3.6	After the IDE has confirmed a successful upload, navigate to Tools > Serial Monitor (Ctrl+Shift+M). The serial monitor should now be displaying EC, TDS, SG, and SAL in raw form at 1.4 second intervals. (Example: 0.00,0.00,0.00,0.00)			
4	Ensure that the carriage return option is selected and that the baud rate is 9600 in the lower right corner of the serial monitor window. At the top of the window, type "C,0". This turns off continuous logging. This command may need to be sent more than once.			
5	Type "RESPONSE,1". This enables response code.			
6	Type "Name,?". The EC EZO will report the name of the device. If brand new, you can name the EC EZO at this stage with the command "Name,xxxxx", where xxxxx is your chosen name.		EC EZO Name:	
7	Type "K,?". This queries the probe type. By default the EC EZO should be set to K1.0, which is needed for seawater applications.		Probe Type:	

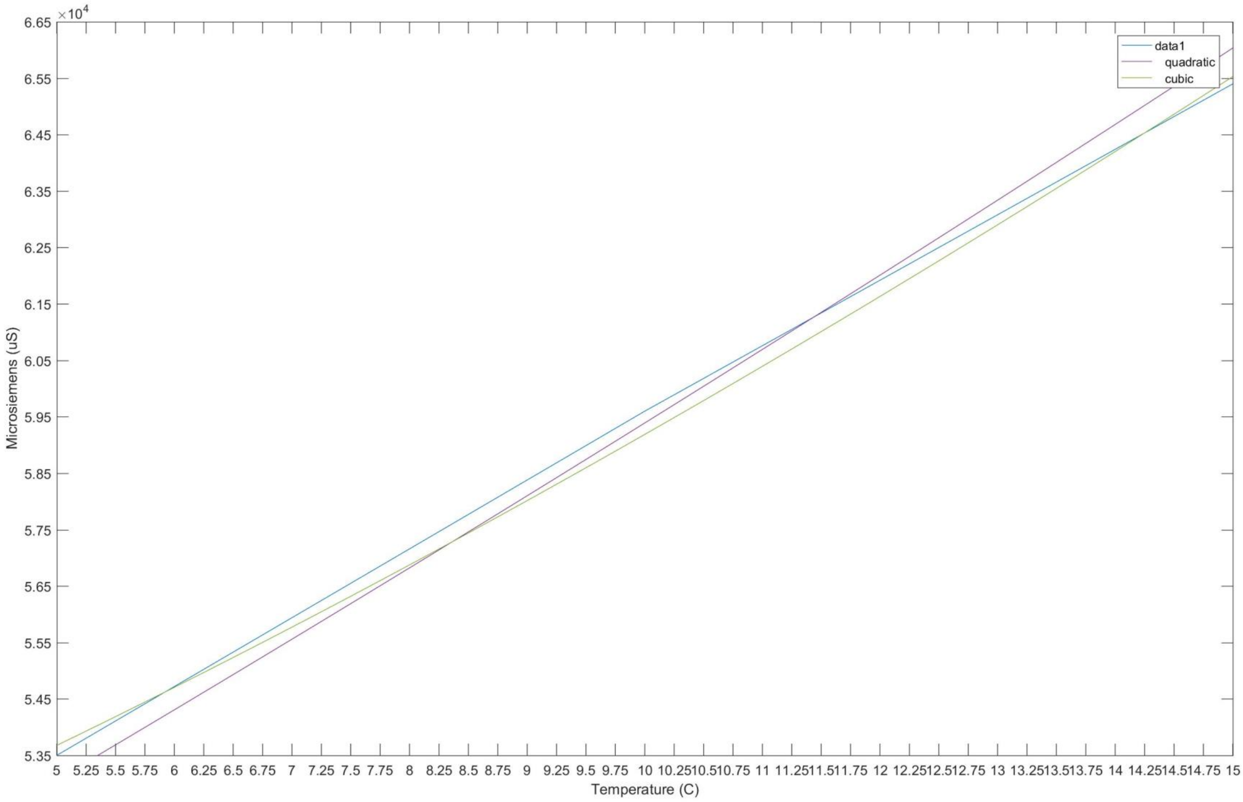
8.1	Type "T,?". This queries the default temperature on the EC EZO. If the EC EZO was recently power cycled, the default temperature will be 25C.			
8.2	Type "T,n". Where n is the temperature of the calibration solution to the nearest hundredth (or ambient temperature if you have allowed the CTD to reach equilibrium with the room it is in).		New Default Temperature:	
8.3	Type “c,1” to re-enable continuous readings.			
9.1	Type "cal,clear". This clears any previous calibration data.			
9.2	Prior to a wet calibration, the probe must be calibrated dry. Type "cal,dry". Wait at least two seconds before proceeding.			
9.3	Place the probe in the lower value calibration solution. Allow the readings to occur until a plateau is reached. Type "cal,low,n". Where n is the lower value calibration solution in uS/cm. This value changes with temperature. No change will be seen in the conductivity reading after giving this command. If successful, the EC EZO will respond with "*OK". To determine n, use the provided Google spreadsheet.		Low n:	
9.4	Remove the probe from the solution, rinse with DI water, and dry.			
9.5	Place the probe in the higher value calibration solution. Allow the probe to sample until a plateau is reached. Type "cal,high,n". Where n is the higher value calibration solution in uS/cm. This value changes with temperature. If successful, the EC EZO will respond with "*OK". To determine n, use the provided Google spreadsheet.		High n:	
9.6	Remove the probe from the solution, rinse with DI water, and dry. Replace any protective caps. Type “c,0” to turn off continuous reading mode.			
9.7	Type "cal,?". This queries the type of calibration saved on the EC EZO. If the two point calibration was successful, the EZO will respond with "?CAL,2"			

10	Type “RESPONSE,0” to turn off the EC EZO response code.			
11	Type "c,1" to enable continuous reading mode.			
12	Type “L,0” to turn off the EC EZO LED. This saves some battery.			
12	Wait at least five seconds. Close the serial monitor window. Upload the operating code to the MKRZero.			


Interpolation Plot - 12880 Solution
×10^4
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
Conductivity (uS/cm)
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
Temperature (degC)


Interpolation Plot - 80000 Solution
×10^4
13
12.8
12.6
12.4
12.2
12
11.8
11.6
11.4
11.2
11
10.8
10.6
10.4
10.2
10
9.8
9.6
9.4
9.2
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
5
Conductivity (uS/cm)
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
Temperature (degC)


data1
quadratic
cubic
10420
10220
10020
9820
9620
9420
9220
9020
8820
8620
8420
8220
Microsiemens (uS)
5
5.25
5.5
5.75
6
6.25
6.5
6.75
7
7.25
7.5
7.75
8
8.25
8.5
8.75
9
9.25
9.5
9.75
10
10.25
10.5
10.75
11
11.25
11.5
11.75
12
12.25
12.5
12.75
13
13.25
13.5
13.75
14
14.25
14.5
14.75
15
Temperature (C)

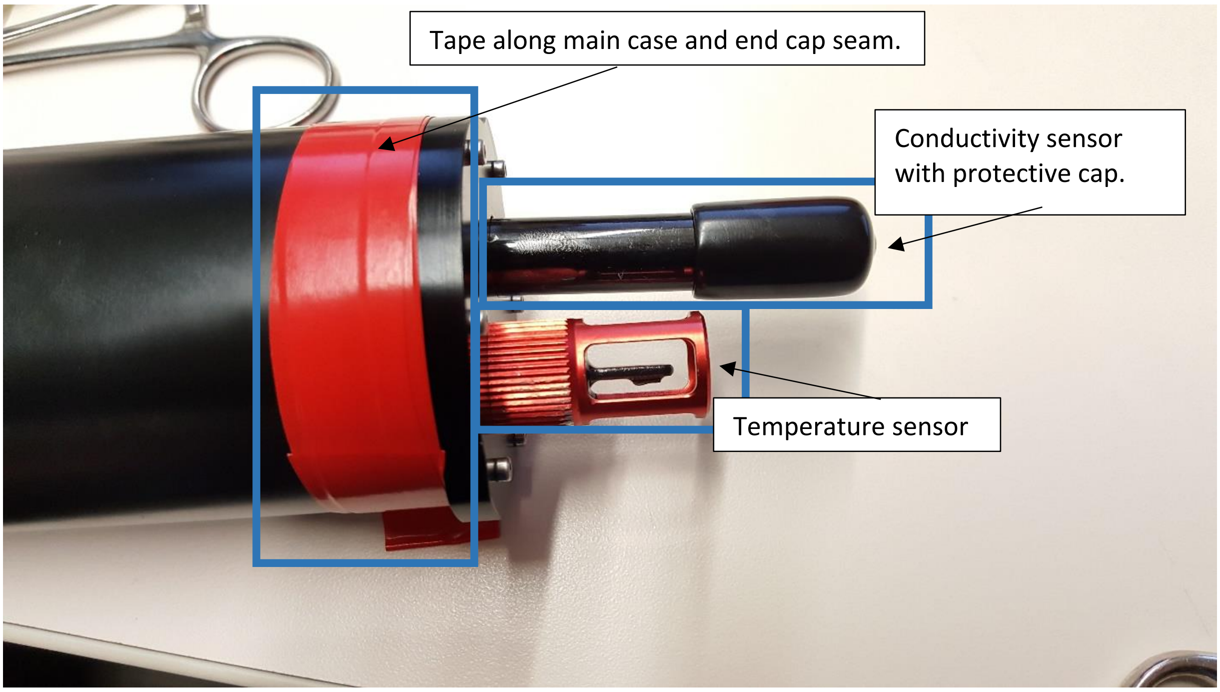


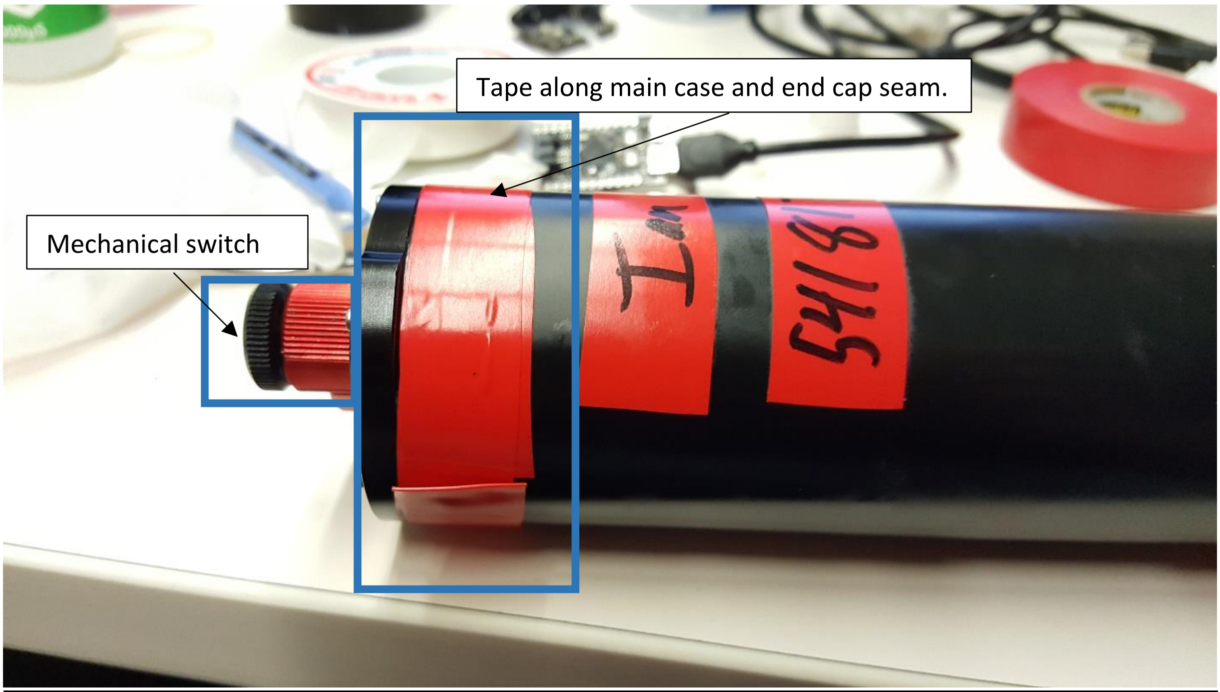
×10^4
6.65
6.55
6.45
6.35
6.25
6.15
6.05
5.95
5.85
5.75
5.65
5.55
5.45
5.35
Microsiemens (uS)
5 5.25 5.5 5.75 6 6.25 6.5 6.75 7 7.25 7.5 7.75 8 8.25 8.5 8.75 9 9.25 9.5 9.75 10 10.25 10.5 10.75 11 11.25 11.5 11.75 12 12.25 12.5 12.75 13 13.25 13.5 13.75 14 14.25 14.5 14.75 15
Temperature (C)
data1
quadratic
cubic

Ian Black
Cell: 541-817-3687
Email: blackia@oregonstate.edu

Deployment Guide

Step 1: Taping the Case
If there is no tape along the cap and case seams, wrap the seam in tape a few times. This helps keep the end cap from rotating. If the main portion of the case is not wrapped in plumbers tape, add a couple layers. This allows any zip ties or c-clamps used to easily grab the CTD.

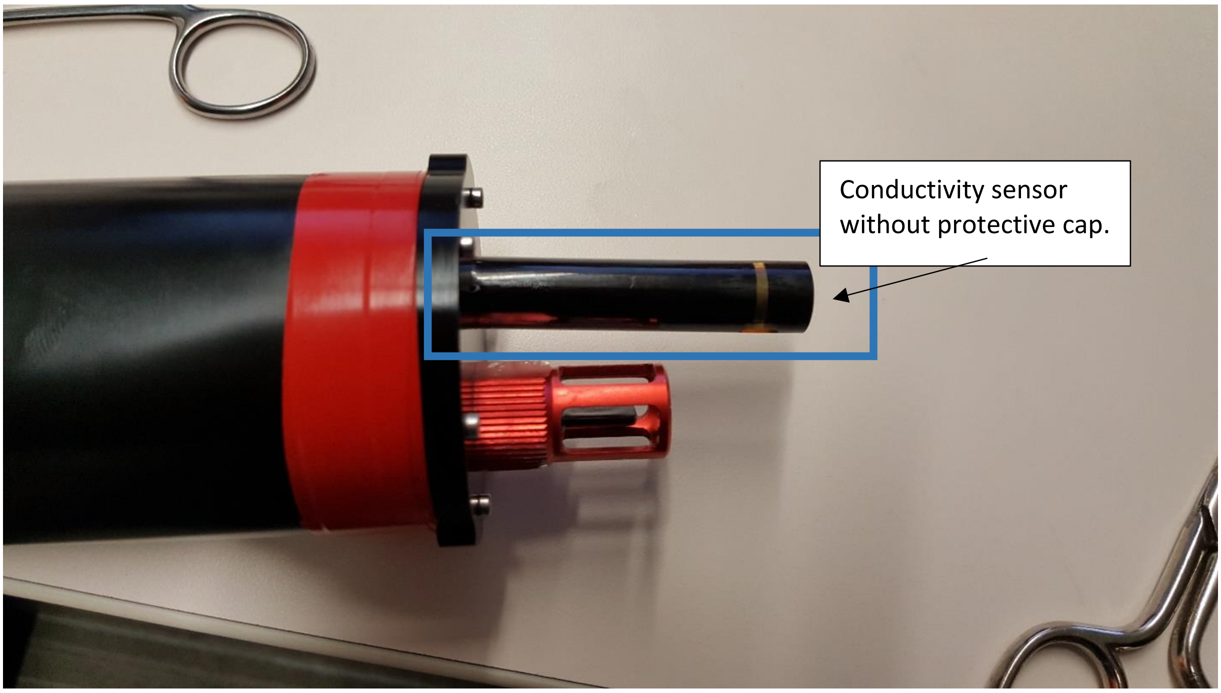




Ian Black
Cell: 541-817-3687
Email: blackia@oregonstate.edu

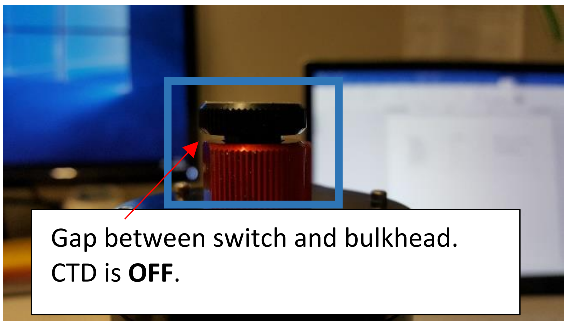
Step 2: Remove Protective Caps

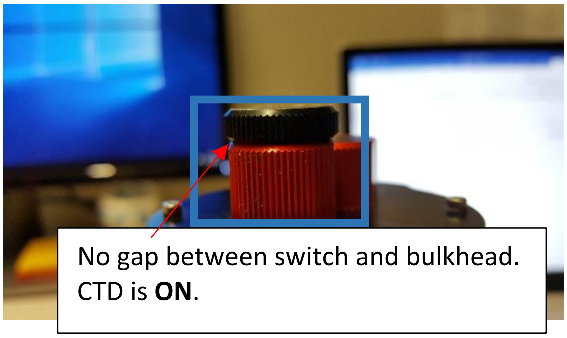
Remove the protective cap from the conductivity sensor.



Step 3: Turning On The CTD

Turn the switch clockwise until it is snug against the bulkhead. It takes about 5 seconds for the CTD to boot up, after which it will immediately start recording data.





Step 4: Attach to Pot or Line

If attaching to a crab pot, ensure that any metal parts of the CTD are not in contact with any metal parts of the pot. Add more plumbers tape if necessary.

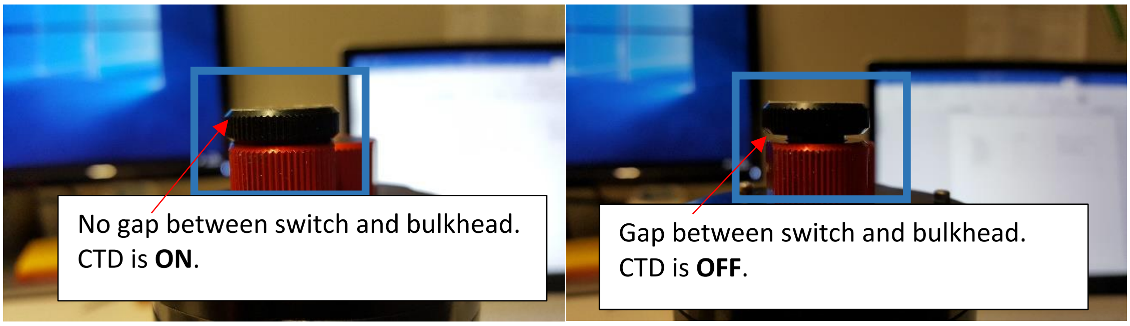
Attach the CTD to the pot or line via zip tie, tape, or strap. If lowering by line, it is recommended that you lower it at a rate of approximately 1ft per second.

Ian Black
Cell: 541-817-3687
Email: blackia@oregonstate.edu

Recovery Guide

Step 1: Detach From Pot Or Line
Cut any zip ties holding the CTD in place.

Step 2: Turning Off The CTD
Turn the switch counterclockwise about 1-2 full rotations. If turned too far, an o-ring may become exposed. If this occurs, turn the switch clockwise until the o-ring is no longer visible.



3: Washing The CTD
If freshwater is available, wash the sensors on the CTD.

Step 4: Sensor Caps and Storage
Replace any protective sensor caps if available. Store the CTD in the provided cases until hand off.

Ian Black
(541) 817 – 3687
blackia@oregonstate.edu

OpenCTD Deployment Log	
CTD Identifier	
Date	
Time	
Latitude	
Longitude	
Depth of Deployment	
Number of Crabs in Pot	
Conditions	
Additional Notes	

Appendix B
Institution Forms

The following forms were approved by the Institutional Review Board at Oregon State University for use in this study.

Flaxen D.L. Conway, Professor and Director,
Marine Resource Management Program
College of Earth, Ocean, and Atmospheric Sciences
Oregon State University, 318 Strand Hall, Corvallis, OR 97331
T 541-737-1339 | fconway@coas.oregonstate.edu

CEOAS
College of Earth, Ocean, and Atmospheric Sciences

Oregon State University

Student Recruitment Guide

Project Title:	Utilizing an Open Source CTD as a Tool for Ocean Education and Research Cooperation
Principal Investigator:	Flaxen Conway
Student Researcher:	Ian Black
Version Date:	August 16, 2017

Hello, my name is Ian Black. I am a graduate student in the Marine Resource Management Program at Oregon State University.

This is an OpenCTD. It measures conductivity, temperature, and depth and allows scientists to determine physical properties of the ocean, such as salinity and density. Commercially produced CTDs are often too expensive for students such as yourselves, as well as amateur oceanographers. The OpenCTD is much cheaper, can be built in a garage, and requires little experience with electronics or computers.

First, I would like to say that we will be asking you to participate in a study. The purpose of the study is to see if building and redesigning the OpenCTD has an impact on your interest in marine science and/or STEM. We will be gauging this by having you take pre- and post-assessment surveys that will be handed out by your teacher. Please note that you don't have to participate in this project if you do not want to. It will not impact your standing in the class.

Over the next couple of months, you will be tasked with constructing and redesigning several open source CTDs. Activities include soldering, Arduino programming, pressure case accessory design, logo design, and troubleshooting of data. After you build the devices and they are tested, local fishermen will use the to collect data for themselves and researchers at Oregon State University.

We aren't quite sure how long it will take you to build these things, but we hope that you have them completed by mid-November 2017. After the devices are built, we hope that you will be able to join us at the Ocean Observing Center in Corvallis to test your devices, as well as interact with the fishermen that will be using them.

You will remain anonymous during the assessment phases of the study and all collected information will be kept confidential. You can skip any of the questions on the questionnaires that you do not feel comfortable answering. If you have any questions, please ask them at this time. Remember that you do not have to participate in the study if you do not want to. If you do decide to participate now, but change your mind later, you can remove yourself from the study by notifying your teacher.

Please ask questions if there is something you do not understand. Thank you for your time!

Flaxen D.L. Conway, Professor and Director,
Marine Resource Management Program
College of Earth, Ocean, and Atmospheric Sciences
Oregon State University, 318 Strand Hall, Corvallis, OR 97331
T 541-737-1339 | fconway@coas.oregonstate.edu

CEOAS College of Earth, Ocean, and Atmospheric Sciences

Oregon State University

Student Assent Form

Project Title:	Utilizing an Open Source CTD as a Tool for Ocean Education and Research Cooperation
Principal Investigator:	Flaxen Conway
Student Researcher:	Ian Black
Version Date:	August 16, 2017

Dear *Student*,

We are asking you whether you want to be in a research study. Research is a way to test new ideas and learn new things. You do not have to be in the study if you do not want to. You can say *YES* or *NO*. If you say yes now, you can change your mind later.

Purpose: The purpose of this study is to help us determine if building an oceanographic instrument in the classroom will have an impact on your interest in science, technology, engineering, or mathematics (STEM). We will ask you to take a pre-assessment and post-assessment questionnaire to help with determining this. The focus of the questions will be on STEM careers, STEM knowledge, and your interest in marine science.

Activities: For this study, we will ask you to work in teams to construct and redesign several open source CTDs. These devices measure conductivity, temperature, and depth, and are considered the workhorse instrument of oceanography. During this project you will participate in activities such as circuit design, soldering, Arduino programming, pressure case design, and the troubleshooting of data. Once you build the devices, they will be given to local fishermen who will collect data for themselves and researchers at Oregon State University.

Time: After reading this cover page, we will ask you to give an informational letter to your parents. After a week has passed, we will then hand out a questionnaire to those who are able to participate in the study. The amount of time it takes for you to build the OpenCTDs will vary based on your redesign, but we would like for them to be completed by mid-November 2017. Around the same time, we hope that you will join us at the Ocean Observing Center in Corvallis to test the instruments as well help teach fishermen how to use them. At the beginning of December 2017, you will be given another questionnaire and the study will end.

Risks: As with any shop or lab class, there is some risk associated with the tools and materials you use. You may have to use power tools and sharp objects to complete the CTD construction. We ask that you use personal protective equipment (PPE) when using tools and soldering. If you have questions or concerns about safety, please direct them to your teacher or the researchers at this time.

Voluntary: You will remain anonymous during the assessment phases of the study and all collected information will be kept confidential. You can skip any of the questions on the questionnaires that you do not feel comfortable answering.

Once we collect the questionnaires, we will write a report. This report will be used to satisfy some of the degree requirements of the student researcher.

If you want to be a part of this study, please sign this form and return it to your teacher.

Remember that you can remove yourself from the study at any time for any reason.

Please ask questions if there is something you do not understand. Thank you for your time!

Participant's Name (printed): ____

____ ________________________________

(Signature of Participant) (Date)

____ ________________________________

(Signature of Person Obtaining Assent) (Date)

Flaxen D.L. Conway, Professor and Director,
Marine Resource Management Program
College of Earth, Ocean, and Atmospheric Sciences
Oregon State University, 318 Strand Hall, Corvallis, OR 97331
T 541-737-1339 | fconway@coas.oregonstate.edu

Dear Student,

If you have any questions regarding the OpenCTD project, the accompanying study, or this survey, please ask them at this time. If there are questions on this survey that you do not want to answer, please feel free to skip them. We thank you for taking the time to answer accurately!

Your Birth Month	**Your Birth Day**	**Initial of Your First Name**

Examples: 10 24 I; 04 21 F; 01 07 R

Q1. Please indicate how much you agree or disagree with each of the statements below.
Check one answer per statement.

"Before building/modifying an OpenCTD"	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I am interested in designing and building instruments used for data collection.					
I am interested in science.					
I am interested in technology.					
I am interested in engineering.					
I am interested in mathematics.					
I am interested in computer science.					
I am interested in learning or working with data.					
I have an understanding of the scientific process.					
I have an understanding of what scientists use conductivity, temperature, and depth for.					
I have knowledge of physical ocean processes that occur in Yaquina Bay and the surrounding ocean.					
I am interested in learning more about ocean science.					
I am interested in a STEM career.					
I am interested in learning more about ocean science careers.					
I am interested in working with tools and equipment. (Example: Soldering iron, mills, lathes, etc)					

Q2. Do you plan on continuing your education after high school? *Please select one.*

- Yes. I plan to attend a university.
- Yes. I plan to attend a community college.
- Yes. I plan to attend a trade school.
- Yes. I plan to join the military.
- No.
- Not sure

Q3. Having been introduced to the OpenCTD project, is there a particular aspect or subject you are interested in learning more about? If so, what?

Thank you! Please return the survey to your teacher once you have finished.
Now let's build some CTDs!

College of Earth, Ocean, and Atmospheric Sciences

Dear Student,
If you have any questions regarding the OpenCTD project, the accompanying study, or this survey, please ask them at this time. If there are questions on this survey that you do not want to answer, please feel free to skip them. We thank you for taking the time to answer accurately!

Your Birth Month	Your Birth Day	Initial of Your First Name

Examples: 10 24 I; 04 21 F; 01 07 R

Q1. Please indicate how much you agree or disagree with each of the statements below.
Check one answer per statement.

"After building/modifying an OpenCTD"	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I am more interested in designing and building instruments used for data collection.					
I am more interested in science.					
I am more interested in technology.					
I am more interested in engineering.					
I am more interested in mathematics.					
I am more interested in computer science.					
I am more interested in learning or working with data.					
I have a stronger understanding of the scientific process.					
I have a stronger understanding of what scientists use conductivity, temperature, and depth for.					
I have more knowledge of physical ocean processes that occur in Yaquina Bay and the surrounding ocean.					
I am more interested in learning more about ocean science.					
I am more interested in a STEM career.					
I am more interested in learning more about ocean science careers.					
I am more interested in working with tools and quipment. (Soldering iron, mills, lathes, etc)					

Q2. Do you plan on continuing your education after high school? *Please select one.*

- Yes. I plan to attend a university.
- Yes. I plan to attend a community college.
- Yes. I plan to attend a trade school.
- Yes. I plan to join the military.
- Not sure
- None of the above. *Please explain:*

Q3. Do you think this OpenCTD project introduced you to a skill that you could apply in the future? (Such as soldering, programming, data analysis, etc.) *Please select one and describe.*

- Yes
- No
- Not Sure

Please describe:

Q4. Do you think this OpenCTD project opened up other career or education opportunities for you? (Such as strengthening of college applications, scholarship, internship, job offer, etc.) *Please select one and describe.*

- Yes
- No
- Not Sure

Please describe:

Q5. How would you rate your overall experience building/modifying an OpenCTD? *Please select one and describe.*

- Excellent
- Good
- Fair
- Poor
- Very Poor

Please describe:

Q6. In what ways, if any, did this experience improve your understanding of a particular subject or concept? *Please explain.*

Q7. In what ways, if any, did this experience change your perception of data and uncertainty? *Please explain.*

Q8. Please share your thoughts on the types of things you may have learned about Yaquina Bay or the surrounding ocean from this project.

Q9. Please share your thoughts about how this project might be be improved. For example, what might be some advice you would you give other students or teachers attempting this project?

Q10. Please share your thoughts about what you enjoyed the most about the project.

Q11. Please share any additional comments.

Thank you! Please return this survey to your teacher once you have finished.

Fisherman Recruitment Guide

Subject: Student researcher seeking input on a research study regarding how to cooperatively build and test a low cost, open source marine technology device that commercial fishermen and others could use to build an understanding of and make decision about the marine environment. This research is a part of a thesis project for a master's in Marine Resource Management at Oregon State University.

My name is Ian Black and I am a graduate student in the Marine Resource Management (MRM) program at Oregon State University.

For my thesis research, I am interested in understanding how fishermen might use ocean condition data gathered by a device (called an OpenCTD) that will be built by a team of Toledo High School students. This device could allow you to collect profile or moored data. How you choose to collect the data is up to you and will depend on the type of data you are interested in. You have ultimate control over how the device is deployed, but I can make suggestions on how to effectively and efficiently collect data based on sensor capabilities, weather, and time. Later, you will have the option to visualize collected data so you can make your own connections between ocean properties and fishing. Suggestions from you about this experience could be used to update future versions of the OpenCTD.

This research project is titled: "**Utilizing an Open Source CTD as a Tool for Ocean Education and Research Cooperation**" and Professor Flaxen Conway, Director of the OSU MRM Program, is the Principal Investigator leading this research project. Our research is supported by a research grant from Oregon Sea Grant, which is interested in the creation of a more accessible ocean condition forecast system.

I am contacting you because I think your perspective would be a valuable addition to this research due to your knowledge and experience regarding the ocean [and your previous work with seacast.org project.] Participation in this study is voluntary. The information you provide will be kept confidential to the extent permitted by law.

I hope you are interested in participating in this project. If so, please let me know your availability for an interview (either in person or over the phone). Please let me know via email at blackia@oregonstate.edu or phone at (541) 817-3687. If you have any additional questions, please get in touch at contact me, or Flaxen Conway at fconway@coas.oregonstate.edu or (541) 737-1339. If you have questions about your rights or welfare as a participant, contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

Thank for your time.
Sincerely,
Ian Black

FISHERMEN VERBAL CONSENT GUIDE

Project Title: ***Utilizing an Open Source CTD as a Tool for Ocean Education and Research Cooperation***

Principal Investigator:	Flaxen Conway
Student Researcher:	Ian Black
Sponsor:	OSU / Oregon Sea Grant
Version Date:	August 2, 2017

Purpose: You are being asked to take part in a research study. The purpose of this research study is to employ a cooperative approach to building and testing a low cost, open source piece of marine technology that local commercial fishermen and others could use to build an understanding of and make decision about the marine environment. This research is a part of a thesis project for a master's in Marine Resource Management at Oregon State University.

Activities: If you take part in this research study via interviews and meetings, you will have the opportunity to use an OpenCTD that was constructed by a Toledo High School student constructed. This device will allow you to collect profile or moored data; how you collect the data will depend on the type of data you are interested in. You will ultimately have control over how the device is deployed, but suggestions will be made on how to effectively and efficiently collect data based on sensor capabilities, weather, and time. Later, you will have the option to visualize collected data so you can make your own connections between ocean properties and fishing. Suggestions from you about this experience could be used to update future versions of the OpenCTD.

Benefit: This study is not designed to benefit you directly, although we hope that the experience of building the OpenCTDs will be helpful to the high school students and the information collected will be helpful to you..

Confidentiality: All participation will remain confidential and all results will be reported in a summaries manner. Participant names will not be used in transcription, analysis, or reporting.

Voluntary: Participation in this study is voluntary. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected and this information may be included in study reports unless you specify that your data is to be excluded. Your decision to take part or not take part in this study will not impact your relationship with the researchers or OSU.

Study contacts: If you have any questions about this research project, please contact:

Flaxen Conway (fconway@coas.oregonstate.edu; 541-737-1339) or
Ian Black (blackia@oregonstate.edu; 541-817-3687)

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Human Research Protection Program (HRPP) office, at (541) 737-8008 or by email at IRB@oregonstate.edu

Fishermen Semi-structured Exit Interview

1. Please describe your reasons for participating in this project
2. Please describe how you deployed the OpenCTD?
3. What did you learn from deploying the OpenCTD?
    a. For example, in what ways has using the OpenCTD improved your knowledge of the ocean?
    b. In what ways were you confident the data represented ocean conditions reasonably? Why or why not?
4. What were some benefits and obstacles experienced during the project?
5. How do you think this project could be improved? What advice would you give others participating in the project?
6. How would you rate your overall experience using OpenCTD?
    a. For example, would you consider building an OpenCTD and collecting data on your own?
    b. Would you recommend the OpenCTD to others in your profession?
    c. Would you be interested in working with the students again?

Thank you!

Appendix C
GitHub Repository

The build guide, the pinout guide, and parts list are in the style of GitHub markdown. The information they provide was last updated on 03/01/2018. For an up-to-date repository, go to: https://github.com/CTDizzle/CTDizzle

The following license is in reference to all of the material hosted on the above link.

Listing C.1: Operating Code

```
/*
This sketch is a combination of code written by the folks at Adafruit, Atlas-Scientific, Blue Robotics, Oceanography For Everyone, Sea-Bird Scientific, and SparkFun.
It is used by the CTDizzle Mk4 and based around the Arduino MKRZero.
Contact Ian Black for any questions regarding this sketch.
Email: blackia@oregonstate.edu

This sketch will print data to a .CSV with 8 columns:
Date , Time , Conductivity , Temperature , Pressure , Depth , Salinity, Density

ISSUES
Assumes atmospheric pressure is 1013 mbar.
Latitude and the autotime function need to be adjusted manually in the sketch.
Latitude should be the latitude at which you anticipate your deployment.
The autotime function needs to be uncommented for the initial upload. Then it needs to be commented out and the sketch uploaded again.
The RTC reverts back to the initial upload time after a power cycle if you do not comment out the autotime function.
*/

#include <SD.h>   //Used by SD module.
#include <SPI.h>   //Used by SD module and RTC.
#include <Wire.h>   //Used by temperature and pressure sensors.
#include "TSYS01.h" //Used by temperature sensor.
#include "MS5837.h" //Used by pressure sensor.
#include <SparkFunDS3234RTC.h> //Used by the RTC.

#define latitude 45.00   //Expected latitude of deployment in decimal degrees. Used in gravity calculation.
#define FluidDensity 1024   //Density in kg/m^3. This varies with water conditions and location.
#define SD_chipselect 28    //Chip select for the MKRZero.
#define RTC_chipselect 7    //Chip select for the DeadOn RTC.

float EC_float = 0, f_ec; //Define conductivity callouts.
char EC_data[48], *EC;
byte received_from_sensor = 0, string_received = 0;
String inputstring = "";

TSYS01 tsensor;//Define temperature callouts.
float t;

MS5837 psensor;   //Define pressure callouts.
float p, depth;

//Salinity coeffiecients and callouts.
```

```
float SalA1=2.070e-5, SalA2=-6.370e-10, SalA3=3.989e-15;
float SalB1=3.426e-2, SalB2=4.464e-1, SalB3=4.215e-1, SalB4=-3.107e-3;
float Salc0=6.766097e-1, Salc1=2.00564e-2, Salc2=1.104259e-4, Salc3=-6.9698e-7, Salc4=1.0031e-9;
float Sala0= 0.0080, Sala1= -0.1692, Sala2= 25.3851, Sala3= 14.0941, Sala4= -7.0261, Sala5= 2.7081;
float Salb0= 0.0005, Salb1= -0.0056, Salb2= -0.0066, Salb3 =-0.0375, Salb4= 0.0636, Salb5= -0.0144;
float Salk =0.0162, SalCStandard=42.914;
float R, RpNumerator, RpDenominator, Rp, rT, RT, s;

//Density coeffiecients and callouts.
float DensB0=8.24493e-1, DensB1=-4.0899e-3, DensB2=7.6438e-5, DensB3=-8.2467e-7, DensB4=5.3875e-9;
float DensC0=-5.72466e-3, DensC1=1.0227e-4, DensC2=-1.6546e-6;
float DensD0=4.8314e-4;
float DensA0=999.842594, DensA1=6.793952e-2, DensA2=-9.095290e-3, DensA3=1.001685e-4, DensA4=-1.120083e-6, DensA5=6.536332e-9;
float DensFQ0=54.6746, DensFQ1=-0.603459, DensFQ2=1.09987e-2, DensFQ3=-6.1670e-5;
float DensG0=7.944e-2, DensG1=1.6483e-2, DensG2=-5.3009e-4;
float Densi0=2.2838e-3, Densi1=-1.0981e-5, Densi2=-1.6078e-6;
float DensJ0=1.91075e-4;
float DensM0=-9.9348e-7, DensM1=2.0816e-8, DensM2=9.1697e-10;
float DensE0=19652.21, DensE1=148.4206, DensE2=-2.327105, DensE3=1.360477e-2, DensE4=-5.155288e-5;
float DensH0=3.239908, DensH1=1.43713e-3, DensH2=1.16092e-4, DensH3=-5.77905e-7;
float DensK0=8.50935e-5, DensK1=-6.12293e-6, DensK2=5.2787e-8;
float t2, t3, t4, t5, s32;
float sigma, Densk, kw, aw, bw, density, val;

//Pressure to depth conversion callouts.
float x, gr;

File datafile;

void setup() {        //Start your engines.
Serial.begin(9600);
delay(10);       //Wait 10 milliseconds before continuing.
Serial1.begin(9600);      //Comms between EC EZO and MKRZero at 9600 bps.
delay(10);
Wire.begin();     //Set up I2C comms.
delay(10);
rtc.begin(RTC_chipselect);   //Enable the RTC.
delay(10);

if (SD.begin(SD_chipselect)) {   //If a SD card is detected on the defined chip select...
char filename[]= "rawCTD00.CSV";
delay (1000);   //Wait a second before continuing.
```

```
for(uint8_t i=0;i<100;i++){
filename[6]=i/10+'0';
filename[7]=i%10+'0';
if(!SD.exists(filename)){ //...create a file with a name in series. Example:
    RAWCTD00.csv, RAWCTD01.csv
datafile=SD.open(filename,FILE_WRITE); //A new file is created when the device
    is power cycled.
break;
}
}
}
else {
Serial.println("No SD card detected. Check your setup."); //Display this message
    if the card is not detected.
return;
}

delay(100);
tsensor.init(); //Initialize the temperature sensor.
delay(100);
psensor.init(); //Initialize the pressure sensor.
delay(100);
psensor.setModel(MS5837::MS5837_30BA); //Define the model of the pressure
    sensor.
psensor.setFluidDensity(FluidDensity); //Set approximate fluid density for
    pressure sensor. Varies with location.

//rtc.autoTime(); //After an initial upload, the RTC will keep the same time as
    your computer. Comment out this line and re-upload to have the RTC maintain
    time.

delay(2000); //Wait two seconds before continuing.
}



void loop() { //And around we go.
rtc.update(); //Update the time.
tsensor.read(); //Read what the temperature is and hold it.
t=tsensor.temperature(); //Define the temperature as a floating point to make the
    salinity and density calculations a little easier.
delay(10);
psensor.read(); //Read what the pressure is.
p=(psensor.pressure()-1013)/100; //Calculate pressure in decibars.
delay (10);

if (Serial1.available()>0){ //If comms with the EC EZO are established
delay(100);
received_from_sensor=Serial1.readBytesUntil(13,EC_data,48); //Read the incoming
```

```
data.
EC_data[received_from_sensor]=0;
delay(300);
}
if ((EC_data[0] >= 48) && (EC_data[0] <= 57)){
print_EC_data();
}

R = ((f_ec/1000)/SalCStandard);     //PSS-78 calculations.
RpNumerator = ( SalA1*p)*( SalA2*pow(p,2))+( SalA3*pow(p,3));
RpDenominator = 1*( SalB1*t)+( SalB2*pow(t,2))+( SalB3*R)+( SalB4*t*R);
Rp = 1+(RpNumerator/RpDenominator);
rT =  Salc0 +( Salc1*t)+( Salc2*pow(t,2))+( Salc3*pow(t,3))+( Salc4*pow(t,4));
RT=R/(rT*Rp);
s = ( Sala0+( Sala1*pow(RT,0.5))+( Sala2*RT)+( Sala3*pow(RT,1.5))+( Sala4*pow(RT
    ,2))+( Sala5*pow(RT,2.5)))+((t-15)/(1+ Salk*(t-15)))*( Salb0+( Salb1*pow(RT
    ,0.5))+( Salb2*RT)+( Salb3*pow(RT,1.5))+( Salb4*pow(RT,2))+( Salb5*pow(RT,2.5)
    ));
delay(10);

//Density Calculation (EOS80)
t2=t*t;
t3 = t*t2;
t4 = t*t3;
t5 = t*t4;
if (s <= 0.0) s = 0.000001;
s32 = pow(s, 1.5);
p /= 10.0;
sigma = DensA0 + DensA1*t + DensA2*t2 + DensA3*t3 + DensA4*t4 + DensA5*t5 + (
    DensB0 + DensB1*t + DensB2*t2 + DensB3*t3 + DensB4*t4)*s + (DensC0 + DensC1*t
    + DensC2*t2)*s32 + DensD0*s*s;
kw = DensE0 + DensE1*t + DensE2*t2 + DensE3*t3 + DensE4*t4;
aw = DensH0 + DensH1*t + DensH2*t2 + DensH3*t3;
bw = DensK0 + DensK1*t + DensK2*t2;
Densk = kw + (DensFQ0 + DensFQ1*t + DensFQ2*t2 + DensFQ3*t3)*s + (DensG0 + DensG1
    *t + DensG2*t2)*s32 + (aw + (Densi0 + Densi1*t + Densi2*t2)*s + (DensJ0*s32))*
    p + (bw + (DensM0 + DensM1*t + DensM2*t2)*s)*p*p;
val = 1 - p / Densk;
if (val) sigma = sigma / val - 1000.0;
delay(10);

//Pressure to depth conversion.
x = sin(latitude / 57.29578);
x = x * x;
gr = 9.780318 * (1.0 + (5.2788e-3 + 2.36e-5 * x) * x) + 1.092e-6 * p;
depth = ((((-1.82e-15 * p + 2.279e-10) * p - 2.2512e-5) * p + 9.72659) * p)/gr;
delay(10);

if (datafile) {
```

```
datafile.print(String(rtc.month()));    //Print month to SD card.
datafile.print("/");
datafile.print(String(rtc.date()));   //print date to SD card.
datafile.print("/");
datafile.print(String(rtc.year())); //Print year to SD card.
datafile.print(",");   //Comma delimited.
datafile.print(String(rtc.hour()));   //Print hour to SD card.
datafile.print(":");
datafile.print(String(rtc.minute()));
datafile.print(":");
datafile.print(String(rtc.second())); //Print date to SD card.
datafile.print(",");   //Comma delimited.
datafile.print(EC);   //Print the floating point EC.
datafile.print(",");
datafile.print(t);   //Print temperature to SD card.
datafile.print(",");
datafile.print(psensor.pressure());   //Print pressure in decibars to SD card.
datafile.print(",");
datafile.print(depth);    //Print depth to SD card.
datafile.print(",");
datafile.print(s);    //Print sketch derived salinity to SD card.
datafile.print(",");
datafile.println(sigma);
datafile.flush();   //Close the file.

Serial.print(String(rtc.month()));    //Print month to SD card.
Serial.print("/");
Serial.print(String(rtc.date()));   //print date to SD card.
Serial.print("/");
Serial.print(String(rtc.year())); //Print year to SD card.
Serial.print(",");   //Comma delimited.
if(rtc.hour()<10){
Serial.print('0');}   //Print a zero for aesthetics.
Serial.print(String(rtc.hour()));   //Print hour to SD card.
Serial.print(":");
if(rtc.minute()<10){
Serial.print('0');}  //Print a zero for aesthetics.
Serial.print(String(rtc.minute()));
Serial.print(":");
if(rtc.second()<10){
Serial.print('0');}  //Print a zero for aesthetics.
Serial.print(String(rtc.second())); //Print date to SD card.
Serial.print(",");
Serial.print(EC);   //Print EC to serial monitor.
Serial.print(",");
Serial.print(t);   //Print temperature to serial monitor.
Serial.print(",");
Serial.print(psensor.pressure());   //Print pressure to serial monitor.
Serial.print(",");
```

```
Serial.print(depth);     //Print depth to serial monitor.
Serial.print(",");
Serial.print(s);     //Print sketch derived salinity to serial monitor.
Serial.print(",");
Serial.println(sigma);
}
delay(600);
}

void print_EC_data(void) {    //Called to parse the incoming data. Strings come in the form of EC,TDS,SAL,GRAV.
EC = strtok(EC_data, ",");
f_ec= atof(EC); //Convert EC to a floating point number to make salinity calculations a little easier.
}
```

Listing C.2: EC Calibration Code

```
//Adapted from the Atlas Scientific sample code by Oceanography For Everyone and modified for use by the MKRZero.
//This sketch is used for communicating with and calibrating the Atlas-Scientific EC EZO.
//The EC EZO may fail to read an initial "C,0", so it may need to be sent more than once to stop continuous reading mode.

byte rx_byte = 0;          //Stores incoming byte.

void setup() {     //Start your engines.
  Serial.begin(9600);     //Baud rate to 9600.
  Serial1.begin(9600);   //EC EZO baud rate to 9600
}

void loop() {
  if (Serial.available()) {      //If a command is sent to the EC EZO from the serial monitor.
    rx_byte = Serial.read();  //The byte becomes that command.
    Serial1.write(rx_byte);    //The byte is sent to the EC EZO.
  }
  if (Serial1.available()) {    //If a information is sent to the MKRZero from the EC EZO.
    rx_byte = Serial1.read();     //The byte becomes the data from the EC EZO.
    Serial.write(rx_byte);     //The incoming value or response is displayed in the serial monitor.
  }
}
```

Listing C.3: MATLAB Processing Script

```
%Running this script, either in MATLAB or as deploytool will process RAWCTD
%files in the form of Date,Time,EC,T,P,Depth,Sal,Density. The script
%ignores the Depth, Sal, and Density values derived by the MKRZero and
%calculates depth and salinity separately.

%Three windows will pop up. 1)Downcast profiles of temperature and
%salinity, 2)Time-series of temperature and salinity, 3)Table of converted
%values.

%This data will also be saved to the C: drive in a folder called
%"OpenCTD_Data" with the date and time as the filename. This version has
%not been tested on Apple hardware, so the directory structure should be
%changed to reflect Apple structuring if using Apple hardware.

%The EC EZO defaults to 25 degrees for temperature compensation. This sketch utilizes a linear EC-temp relationship to derive a
%temperature compensated EC value. This is based on the assumption that the
%temperature compensation factor is 0.02. This is an adequate assumption
%in 0-30 degC waters per Hayashi 2003.

[filename, pathname] = uigetfile({'*.csv';'*.txt'},'Select OpenCTD Data'); %Open a search window.
filepath=fullfile(pathname,filename);   %Holds location of chosen file.
Data=readtable(filepath,'Delimiter',',','Format','%{MM/dd/uuuu}D %{HH:mm:ss}D %f %f %f %f %f %f','HeaderLines',0,'ReadVariableNames',false); %Read the csv and create a data array with eight columns.

Date=table2array(Data(:,1));  %Create a Date array.
Time=table2array(Data(:,2));  %Create a Time array.
CnvtDT=@(Date,Time) datetime([Date.Year Date.Month Date.Day Time.Hour Time.Minute Time.Second], 'Format', 'MM.dd.yy HH:mm:ss');
DateTime=CnvtDT(Date,Time);   %Create a DateTime array.
EC=table2array(Data(:,3));    %Create an EC array in uS/cm.
T=table2array(Data(:,4));     %Create a T array in degC.
P=table2array(Data(:,5));     %Create a P array in millibars.

for L=length(DateTime)  %This will smooth data based on the amount collected (assuming 1Hz sampling rate).
if L <= 50     %If there is less than ten minutes of data...
MovValue = 5;       %k=10
elseif L > 50 && L <= 200  %If there is less than two hours but more than 10 minutes of data...
MovValue = 10;       %k=30
else
MovValue = 25;      %k-300
end %Determines the k value for the moving mean based on number of samples taken.
end
```

```

%PSS-78 Coefficients (See AN14 by SeaBird Scientific)
A1=2.070*10^-5; A2=-6.370*10^-10; A3=3.989*10^-15;
B1=3.426*10^-2; B2=4.464*10^-1; B3=4.215*10^-1; B4=-3.107*10^-3;
c0=6.766097*10^-1; c1=2.00564*10^-2; c2=1.104259*10^-4; c3=-6.9698*10^-7; c4=1.0031*10^-9;
a0=0.0080; a1=-0.1692; a2=25.3851; a3=14.0941; a4=-7.0261; a5=2.7081;
b0=0.0005; b1=-0.0056; b2=-0.0066; b3=-0.0375; b4=0.0636; b5=-0.0144;
k=0.0162; CStandard=42.914;
CompEC = EC.*(1+0.01.*(T-25));

latprompt = {'Enter the deployed latitude in decimal degrees.'}; %Create a prompt window asking for latitude.
dlg_title= 'Latitude';
num_lines = 1;
defaultans = {'45.00'}; %Display the default latitude as 45.00 deg.
latitude = cell2mat(inputdlg(latprompt,dlg_title,num_lines,defaultans)); %Store the latitude value.

AtmP=P(1,1);  %Determine atmospheric pressure from the first pressure value.
p=(P-AtmP)./100;  %Calculate gauge pressure in decibars.
x=sin((latitude(1,1))/57.29578);
y=x.*x;
gr = 9.780318 .* (1.0 + (5.2788e-3 + 2.36e-5 .* y) .* y) + 1.092e-6 .* p;
D_meters = ((((-1.82e-15 .* p + 2.279e-10) .* p - 2.2512e-5) .* p + 9.72659) .* p)./gr;


%Salinity Calculations (See AN14 by Seabird Scientific)
R=((CompEC/1000)/CStandard);
RpNumerator=(A1*p)+(A2*(p).^2)+(A3*(p).^3);
RpDenominator=1+(B1.*T)+(B2.*T.^2)+(B3.*R)+(B4.*T.*R);
Rp=1+(RpNumerator./RpDenominator);
rT=c0+(c1.*T)+(c2.*T.^2)+(c3.*T.^3)+(c4.*T.^4);
RT=R./(rT.*Rp);
S=(a0+(a1.*RT.^0.5)+(a2.*RT)+(a3.*RT.^1.5)+(a4.*RT.^2)+(a5.*RT.^2.5))+((T-15)./(1+k.*(T-15))).*(b0+(b1.*RT.^0.5)+(b2.*RT)+(b3.*RT.^1.5)+(b4.*RT.^2)+(b5.*RT.^2.5));  %Gives salinity in PSU.

Filter1=horzcat(D_meters,T,S);
ind = Filter1(:,1)<1;
Filter2=removerows(Filter1,'ind',ind); %Cleaned up data array.
[M, I]=max(Filter2(:,3));
Downcast = horzcat(Filter2(1:I,1),Filter2(1:I,2),Filter2(1:I,3)); %D,T,S
MovS = movmean(Downcast(:,3),MovValue,'omitnan');  %Calculate the moving mean for salinity.
MovT = movmean(Downcast(:,2),MovValue,'omitnan');  %Calculate the moving mean for temperature.

```

```
NAMECNVT=@(Date,Time) datetime([Date.Year Date.Month Date.Day Time.Hour Time.
    Minute Time.Second], 'Format', 'yyyy-MM-dd_HHmm');
NAME=NAMECNVT(Date,Time);
NEWFILENAME=char(NAME(1,1));

cd C:\
mkdir OpenCTD_Data
cd C:\OpenCTD_Data
mkdir (NEWFILENAME)
cd (NEWFILENAME)

%Create plots of profiles
figure('Name','Profiles','NumberTitle','off');
subplot(121) %Temperature Profile
scatter(MovT,Downcast(:,1),'r.')
hold on
xlabel('Temperature (degC)')
ylabel('Depth (meters)')
title('Temperature Profile')
set(gca,'Ydir','reverse')
hold off

subplot(122) %Salinity Profile
hold on
scatter(MovS,Downcast(:,1),'b.')
xlabel('Salinity (PSU)')
ylabel('Depth (meters)')
title('Salinity Profile')
set(gca,'Ydir','reverse')
hold off

profname=char(strcat({NEWFILENAME},{'_Profiles'}));
saveas(gcf,profname,'jpeg')

%Create time-series plots.
figure('Name','Time-Series','NumberTitle','off');
subplot(311)    %Temperature Time-Series
hold on
plot(DateTime,T*1.8+32,'r','LineWidth',2)
xlabel('Date and Time')
ylabel('Temperature (degF)')
title('Temperature Time-Series')
hold off

subplot(312)
hold on
plot(DateTime(5:end),MovS(5:end),'b','LineWidth',2)    %Salinity Time-Series
xlabel('Date and Time')
ylabel('Salinity (PSU)')
```

```
title('Salinity Time-Series')
hold off

subplot(313)
hold on
plot(DateTime(5:end),D_meters(5:end)*0.546,'k','LineWidth',2)   %Depth Time-Series
xlabel('Date and Time')
ylabel('Depth (fathoms)')
title('Depth Time-Series')
set(gca,'Ydir','reverse')
hold off

seriesname=char(strcat({NEWFILENAME},{'_TimeSeries'}));
saveas(gcf,seriesname,'jpeg')


%Display table of downcast data.
f=figure('Name','Table','NumberTitle','off');
t=uitable(f);
t.Data= Downcast;
t.ColumnName={'Depth (m)','Temp (degC)','Salinity (PSU)'};
t.ColumnEditable=false;
set(t,'Units','inches','Position',[0 0 4 4],'ColumnWidth',{105})

name=char(strcat({NEWFILENAME},{'_Processed'},'.csv'));
csvwrite(name,Downcast);
```

Listing C.4: R Processing Script

```r
#This brief R script will take your raw CTD data and create temperature and salinity downcast profiles.
#For questions or suggestions, contact Ian Black (blackia@oregonstate.edu).
#Feel free to modify this script as you see fit.

#ISSUES
#Does not consider the latitudinal variation in gravity.
#Assumes that the first recorded pressure value is representative of the atmospheric pressure.

setwd('C:/OpenCTD_Data') #Set working directory to user-created folder in C drive named "OpenCTD_Data". You can still search for the file elsewhere through a search window per the script.
originalcolumns <- c("Date","Time","Conductivity","Temperature","Pressure","Depth","Sal","Density") #Establish column names for incoming file read.
rawdata <- read.csv(file.choose(),header=FALSE,skip=3,col.names=originalcolumns,stringsAsFactors=FALSE)  #Read user transferred file from the user-defined working directory. Removed the first three lines in case of gibberish from EC circuit.

#Coefficients for Pressure to Depth Conversion (See AN69 by SeaBird Scientific)
Coeff1=-1.82*10^-15; Coeff2=2.279*10^-10; Coeff3=2.2512*10^-5; Coeff4=9.72659; g=9.806

#Calculating Depth from Absolute Pressure (See AN69 by SeaBird Scientific)
AtmP = rawdata[1,5] #Assuming first recorded pressure value is the atmospheric pressure.
GaugeP = matrix((rawdata[,5]-AtmP)/100)
Depth = matrix(((((Coeff1*GaugeP+Coeff2)*GaugeP-Coeff3)*GaugeP+Coeff4)*GaugeP)/g)

#PSS-78 Coefficients (See AN14 by SeaBird Scientific)
A1=2.070*10^-5; A2=-6.370*10^-10 ; A3=3.989*10^-15
B1=3.426*10^-2; B2=4.464*10^-1; B3=4.215*10^-1; B4=-3.107*10^-3
c0=6.766097*10^-1; c1=2.00564*10^-2; c2=1.104259*10^-4; c3=-6.9698*10^-7; c4=1.0031*10^-9
a0=0.0080; a1=-0.1692; a2=25.3851; a3=14.0941; a4=-7.0261; a5=2.7081
b0=0.0005; b1=-0.0056; b2=-0.0066; b3=-0.0375; b4=0.0636; b5=-0.0144
k=0.0162; CStandard=42.914

#PSS-78 Calculations for Salinity (See AN14 by SeaBird Scientific)
R=matrix((rawdata[,3]/1000)/CStandard)
Rp=1+(((A1*GaugeP[,1])+(A2*(GaugeP[,1])^2)+(A3*(GaugeP[,1])^3))/(1+(B1*rawdata[,4])+(B2*rawdata[,4]^2)+(B3*R)+(B4*R*rawdata[,4])))
rT=c0+(c1*rawdata[,4])+(c2*rawdata[,4]^2)+(c3*rawdata[,4]^3)+(c4*rawdata[,4]^4)
RT=R/(rT*Rp)

#Calculating Salinity
```

```
Salinity=(a0+(a1*RT^0.5)+(a2*RT)+(a3*RT^1.5)+(a4*RT^2)+(a5*RT^2.5))+((rawdata[,4]-15)/(1+k*(rawdata[,4]-15)))*(b0+(b1*RT^0.5)+(b2*RT)+(b3*RT^1.5)+(b4*RT^2)+(b5*RT^2.5))

ConvertedData <- matrix(c(c(rawdata[,4]),c(Salinity),c(Depth)),ncol=3)
Filter1 <- ConvertedData[-which(ConvertedData[,3]<=1.0),] #Remove top meter of data.
MaxDepth <- which.max(Filter1[,3])     #Determine maximum depth reached.

DowncastTemp <- matrix(Filter1[1:MaxDepth,1]) #Create a new matrix with data only between the top and max depth.
DowncastSal <- matrix(Filter1[1:MaxDepth,2])
DowncastDepth <- matrix(Filter1[1:MaxDepth,3])

win.graph(800,600)  #Set window size for plots.
par(mfrow=c(2,1)) #Display both profiles in one window.
plot(DowncastTemp,-DowncastDepth,xlab='Temperature (C)',ylab='Depth (m)',col='#ff3300')  #Plot temp profile of downcast.
plot(DowncastSal,-DowncastDepth,xlab='Salinity (PSU)',ylab='Depth (m)',col='#0066ff')  #Plot sal profile of downcast.
```

CTDizzle User Manual

Other Links
[Parts List](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/MKRZero_Parts_List.md)

[Code](https://github.com/CTDizzle/CTDizzle/tree/master/MKRZero/ArduinoFiles)

[Pinout Guide](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/MKRZero_Pinouts.md)

[Resources and Literature](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Resources.md)

[EC Cal Procedure](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/EC_Cal_Procedure.docx)

[Data Processing](https://github.com/CTDizzle/CTDizzle/tree/master/Data%20Processing)

Guide Contents

Introduction

Oceanographic equipment is often expensive and inaccessible for students and citizen scientists. The OpenCTD is a relatively cheap, buildable device that allows individuals to easily collect conductivity, temperature, and pressure data. It is still being refined and doesn't quite produce research quality data, but in its current state it is a great tool for teaching and learning.

Check out the [original OpenCTD](https://github.com/OceanographyforEveryone/OpenCTD) if you want to build a lower cost device using easily accessible materials and tools. Many thanks to Andrew Thaler, Kersey Sturdivant, and Russell Neches for providing the initial framework for the OpenCTD.

![Original
OpenCTD](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/OpenCTDVersions.jpg)
Variations of the original OpenCTD. Photo taken by Andrew Thaler.

Before You Get Started

This guide was written so that you can build your very own CTDizzle. If you are confused on a topic, or require additional information, please do not hesitate to contact Ian Black (blackia@oregonstate.edu) if you are unable to find what you need in your own research.

There are likely cheaper and better sensor options out there. This guide only covers the parts outlined in the parts list. If you decide to use different sensors or parts, it is your responsibility to ensure that all parts are compatible with your setup.

It should be noted that this guide assumes that you are running everything through Windows. As such, there is no Linux or macOS support for the MATLAB and R processing scripts at this time. Please make sure that you are able to find an equivalent program or script modification for the steps that use third-party programs.

Why Conductivity, Temperature, and Depth?

Temperature itself is incredibly useful as so many other ocean properties and phenomena are impacted by it.
One study suggests that rockfish prefer to hang out in a certain water temperature range. Commercial trawls in Alaska and Oregon have reported a greater abundance of the fish in temperatures ranging between 4 and 7 degC ([Vestfals, 2010](http://ir.library.oregonstate.edu/xmlui/handle/1957/12047?show=full)). Many other studies show that temperature also impacts the growth rate, welfare, and reproductive potential of other marine organisms. Temperature also influences factors such as water density, pH, and how much gas seawater can hold. By monitoring ocean temperature over space and time, scientists are able to come up with connections between temperature and other aspects of our oceans.

Conductivity by its lonesome isn't a particularly useful, but when combined with temperature and pressure through some empirical calculations, you can get values such as salinity, density, and sound velocity. Salinity is essentially the concentration of dissolved salts in the water. Salty, cold water is more dense than fresh, warm water, and this is easily seen in the Columbia River plume. During the winter, the Columbia River outputs a lot of freshwater. This freshwater can form a layer that is about 20m thick and extends almost 300km offshore ([Saldias et al, 2016](http://onlinelibrary.wiley.com/doi/10.1002/2015JC011431/full)). The density of this plume is low enough that there have been cases where gliders have become stuck between the layers!

Depth is sometimes difficult to measure. The average depth of the ocean is 4000m, with the deepest part reaching almost 11000m. That would be a long tape measure! Scientists have come up with a variety of methods for measuring depth, such as sonar measurments, satellite altimetry, and pressure readings. The CTD uses pressure to determine water depth, which is easily calculated through an empirical formula.

The CTD is the workhorse tool of oceanography. By building your own, I hope that you gain an appreciation for the science, how it is collected and used, and what it tells us about our oceans.

The CTDizzle Mk4

This is the fourth rendition of the CTDizzle. Its construction is a little different from the original OpenCTD, as it uses some different sensors and parts. It costs about 700 USD to build and doesn't require any tools that can't be easily found at your local hardware store. If you have all the parts and tools on hand, you should be able to build it in a weekend!

`![Versions](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/Versions.jpg)`
Left to Right: CTDizzle Mk1, Mk3, and Mk4. The Mk2 is currently being used as a doorstop

Specifications
* Theoretical Max Depth: 200m
* Tested Depth: 80m
* Conductivity Accuracy: +/- 2% after calibration
* Temperature Accuracy: +/- 0.1 C
* Pressure Accuracy: +/- 100 mbar
* Max Sampling Rate: 1 Hz
* Battery Life: ~ 60 hours sampling at 1 Hz (3.7v 2200 mAh)

Battery life ultimately depends on the battery that you use. It is recommended that you stick with the 3.7v LiPo JST-PH connector family.

Build Instructions

Software Setup
Setting Up the Arduino IDE
The Arduino Integrated Development Environment (IDE) is simple to use. It is recommended that you maintain the default directories that the Arduino IDE download wizard creates. To install Arduino…

1. Go to https://www.arduino.cc/en/main/software.
2. Select the Windows Installer version.
3. Follow the installation wizard.
4. Set up shortcuts as desired.

Setting up the MKRZero
The MKRZero was designed and is officially supported by Arduino. The required package does not come pre-installed with the Arduino IDE, so you will need to install it using the Boards Manager.

1. Open the Arduino IDE.
2. Navigate to Tools > Board > Board Manager
3. Search for "Arduino SAMD Boards". Select Install.
4. After it has installed, navigate to Tools > Boards.
5. Select MKRZero.
6. Connect your MKRZero to your computer via microUSB.
7. Navigate to Tools > Port. Select the available COM Port.

Your MKRZero should now be upload ready. It is recommended that you keep track of which USB port you plugged the MKRZero into. That way you don't have to worry about changing the com port every time you connect it to the computer.

Formatting the SD Card
It is also necessary to format the microSD card that will be used to store the data.

1. Insert the microSD card into a USB adapter and plug into a computer.
2. Navigate to Windows Explorer, right click your microUSB card and select Format.
3. Under file system, select FAT.
4. Select Start.
6. Your card should now be formatted.

7. OPTIONAL: Navigate to your SD card through Windows Explorer. If desired create and additional folder to save old data.

Another option is to install the [SD Card Formatter](https://www.sdcard.org/downloads/formatter_4/) developed by the SD Association. This application is particularly useful if you like to tinker with the Raspberry Pi.

Setting Up the Required Libraries
Several libraries are needed to allow the CTDizzle operating code to work. These libraries allow communication with the sensors and the use of unique commands. They can either be found within the Arduino IDE or downloaded from GitHub. Libraries native within the IDE are automatically included by the IDE and no further steps are necessary to include them. The following instructions show how to download and access the third party libraries.

Native Libraries	Third Party Libraries
SPI	TSYS01
Wire	MS5837
SD	SparkFunDS3234RTC

TSYS01 Temperature and MS5837 Pressure Sensor Libraries
The temperature sensor requires the TSYS01 library. The pressure sensor requires the MS5837 library. To access the libraries:
1. In the Arduino IDE, navigate to Sketch > Include Library > Manage Libraries.
2. In the search bar, type "BlueRobotics".
3. Click on the BlueRobotics TSYS01 Library. Select Install.
4. Click on the BlueRobotics MS5837 Library. Select Install.
5. These libraries are now automatically included when using the operating code.

DeadOn RTC Library
The DeadOn RTC requires the SparkFunDS3234RTC library. To access the library:
1. Go to https://github.com/sparkfun/SparkFun_DS3234_RTC_Arduino_Library.
2. Select the Clone or download button. Click on Download Zip.
3. In the Arduino IDE, navigate to Sketch > Include Library > Add .ZIP Library.
4. Go to Downloads. Select the SparkFun_DS3234_RTC_Arduino_Library-master folder.
5. The DeadOn RTC library is now available for use. Note that during future uploads, the Arduino IDE may classify the DeadOn RTC library as “Uncategorized”. The library should still function even though this message appears.

If you are using different sensors, make sure to use the right libraries!

Breadboard Testing

Tools	Protective Equipment
Soldering Iron	Eye Pro
Hemostats	Nitrile Gloves
Wire Strippers
Breadboard
Third Hand

Most of the parts are already breadboard compatible, but you will need to solder header pins to the DeadOn RTC. If you aren't familiar with soldering, take the time to practice with some header pins and protoboard. It is recommended that you use hemostats or tweezers to cleanly break the header pins. You'll use less solder than you first expect and it will happen pretty quickly. Once you think you are ready, solder some header pins to the DeadOn RTC! It isn't necessary, but if you want your solder job to be nice and shiny, you can use a soft bristle brush and some alcohol to wipe away the excess flux.

Here is [SparkFun's Guide to Soldering Through-Holes](https://learn.sparkfun.com/tutorials/how-to-solder-through-hole-soldering) if you need a tutorial.

![Picture of DeadOn RTC with header pins
here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/SolderedRTC.jpg)
DeadOn RTC with soldered headers.

Next you need to prepare the temperature and pressure sensors. Remove the DF13 connects from each sensor. Then strip away roughly 1cm of insulation on each of the wires and tin the ends to prevent loose strands.

![Picture of exposed wire
here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/Pressure.jpg)
Trimmed pressure sensor wires.

Both the temperature and pressure sensors use I2C to communicate with the MKRZero and share the same pinouts. Each device has a unique address, so the MKRZero is capable of differentiating between the two. For the bench testing phase, it is okay to connect similar wires with a single alligator clip.

Now is the time to set things up on the breadboard!
Place the MKRZero, EC EZO, and DeadOn RTC on the breadboard. Don't forget to install the SD card and coin cell!

![Picture of setup
here](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/BareBreadboard.jpg)
Board setup before all the messy jumper wires.

Connect everything together as outlined in the pinout guide. Remember that VCC in this scenario is 3.3v. Under no circumstances should you connect the temperature sensor, pressure sensor, or DeadOn RTC to the 5v supply on the MKRZero. You will likely fry the electronics, and then you would be out ~$144!

Here is the [Sparkfun Guide to Using a Breadboard](https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard).

Here is the [SparkFun Guide to Circuitry](https://learn.sparkfun.com/tutorials/what-is-a-circuit).

Sensors and Pinouts

You can power the MKRZero through a 5v source or a 3.7v LiPo battery. For breadboard testing, you'll want to hook up the MKRZero to your computer via microUSB cable. It should be noted that most of the accessory boards are only 3.3v tolerant. You should only hook the boards up to VCC and not the 5v pin.

For the pinouts, you'll see the name of the boards at the head of each table. You'll want to connect one pin on the left side to the other pin on the right side. Take the CLK pin on the DeadOn RTC for example. You'll want to connect this pin to the SCK (pin 9) on the MKRZero.

Common Pins

GND - This is your ground pin. Commonly seen as the negative (-) on a battery. It is essential for ensuring that your circuit is complete and safe. If you do not properly ground a device, you increase the risk of damage or electrical shock.

VCC - This is your power supply pin. Commonly seen as the positive (+) on a battery. It is essential for powering the devices.

TX - This is the transmit pin of your device. This is the pin that sends data during serial communication.

RX - This is the receive pin of your devices. This is the pin that receives data during serial communication. If sending data from one device to another, you'll hook up the Tx line of the sending device to the Rx line of the receiving device.

SCL - This is the clock line, which allows the MKRZero to tell the device when to send data.

SDA - This is the data line. It allows the device to send data to the MKRZero.

The DeadOn RTC

The DeadOn RTC (the red board with the battery holder) is what allows the CTD to maintain time even when powered off. You'll want to connect each pin on the RTC to the MKRZero as follows. For VCC and GND, you can connect them to the + and - on the breadboard, as you will need to power multiple boards at once. SQW is not needed because we only want the RTC to keep time. If you wanted to add an alarm, you could implement the SQW pin.

DeadOn RTC	MKRZero
GND	GND
VCC	VCC
SQW	Not Applicable
CLK	9 (SCK)
MISO	10 (MISO)
MOSI	8 (MOSI)
SS	D7

The SD Card

SD capabilities are native to this board. No soldering or connections needed here. This pin is called out in the operating code.

Board SD	MKRZero
CS	28

The Temperature Sensor

The TSYS01 temperature sensor (the aluminum sensor with the cage) communicates with the MKRZero via the I2C communication protocol. You'll notice in the pressure sensor section that the pinouts are the same as the temperature sensor. This is okay, as each sensor has a unique address that allows the MKRZero to tell the difference between the two.

TSYS01 Temperature Sensor	MKRZero
Red	VCC
Black	GND
Green	12 (SCL)

|White|11 (SDA)|

The Pressure Sensor

The MS5837 pressure sensor (the aluminum sensor with the flat top) also communicates with the MKRZero via I2C. For the breadboard testing phase, you can connect the green wires of the pressure and temperature sensor together, the white wires together, etc..

MS5837 Pressure Sensor	MKRZero
Red	VCC
Black	GND
Green	12 (SCL)
White	11 (SDA)

The EC EZO Circuit

The EC EZO (the green board with the epoxy layer) is what controls the EC probe and sends data to the MKRZero. This board communicates via Universal Asynchronous Receiver/Transmitter (UART). This is a complex board, and it is possible to program it seperately using the MKRZero. You will do this later when you calibrate conductivity sensor.

EC EZO	MKRZero
Tx	13 (Rx)
Rx	14 (Tx)
VCC	VCC
GND	GND

TX on one side connects to RX on the other. TX should never attach to TX.

The EC Probe

The EC Probe is not actively powered. Instead, the EC EZO drives a voltage on PRB1. As seawater bridges the gap in the probe, current will pass to PRB2 and the EC EZO will be able to calculate conductivity.

Atlas-Scientific EC K1.0 Probe	EC EZO
Red	PRB1
Black	PRB2

After you cut the EC probe cable, the lead to PRB orientation does not matter. It is important that you make sure that the probe leads do not interact. If you are concerned that your pins may short, use a multimeter to check the connectivity.

Most of the modules can be connected with the standard M/M jumper wire. For the temperature and pressure sensors you will need to use some alligator clips to make the proper connections. The EC probe will need to connected to the EC circuit via the BNC connector. Note that the BNC connector will need to be cut later, but for the bench test and calibration stages, it is okay to leave it on.

![Picture of setup with jumper wires
here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/MessyWires.jpg)
Board setup with jumper wires.

After you double check the connections it is time to fire it up! Connect your MKRZero to the computer and upload the MKRZero_OpCode.
Make sure the rtc.autotime() function is uncommented for the first upload. After the first upload, comment out the rtc.autotime() function and re-upload. We do this so that the RTC maintains the time instead of reverting back to the original upload time evertime it loses power.

Open the serial monitor (Ctrl+Shift+M). If you have everything set up correctly, you should see data printing to the screen in the form of:

Date (mm/dd/yyyy), Time (HH:mm:ss), Conductivity (uS/cm), Temperature (degC), Absolute Pressure (mbar), Depth (m), Salinity (PSU)

`![Picture of output.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/SerialMonitorOutput.PNG)`
Date,Time,EC,T,P,Depth,Salinity

The date and time should be close to the time that your computer is set to. It may be off by about 30-60 seconds due to upload delay. If your time is drastically off or incoherent, remove the battery and power cycle the system. Note that the autotime function will need to be commented out of the code for the final sketch upload or else your CTD will revert to the same time on a power cycle.

The conductivity value should be zero. If it is not present in the output, try switching the Tx and Rx lines. If for some reason you begin to see ASCII or random letters in your EC output, try putting the probe in a cup of tap water. Sometimes the EC circuit can be upset by the electrical noise of the probe.

The temperature should be representative of the ambient temperature of the room you are performing the test in. It may be handy to have a thermometer nearby to check this. The temperature probe is factory calibrated, but if further calibration is needed, a two-point calibration is recommended.

The pressure sensor should be spitting out values between 1000 and 1050 depending on your elevation and sensor accuracy. At sea level, atmospheric pressure is around 1013 mbar. The pressure sensor is factory calibrated, but if values appear to be drastically off, first check your pinout connections. If still incorrect, contact the manufacturer.

Depth is sketch-derived using the empirical equation outlined in [UNESCO Marine 44](http://unesdoc.unesco.org/images/0005/000598/059832eb.pdf). For the CTDizzle, there is no consideration for latitude, so gravity is assumed to be 9.806 m/s^2. It is also assumed that atmospheric pressure is 1013 mbar. For your bench tests you can ignore this value.

Salinity is also sketch-derived per the same paper. You can also ignore this value during bench tests.

Don't forget to check the output on the SD card! Pull the card, put it in and adapter and plug it into your computer. Opening up the SD card in Windows explorer should give you a window similar to this..

`![USB](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/USBPopup.PNG)`
Note that a good way to see if you collected data is to look at the file size. Files with ~5 kb are representative of a deployment that lasted a few minutes. The file with ~4000 kb is representative of a deployment that lasted about 24 hours.

Opening up one of the .csv files will give you...

`![CSV](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/CSVOutput.PNG)`
The data format is the same as the format in the serial monitor. This was opened in MS Excel.

Once you are finished checking everything, reinstall the microSD card. Now it is time to calibrate the conductivity probe!

Calibrating Conductivity

Tools	Protective Equipment
Small Plastic Cup	Nitrile Gloves

Unlike the factory calibrated temperature and pressure sensors, the conductivity kit requires a user calibration. First, you will need to leave your complete setup and calibration solutions in a temperature controlled room over night. You might also be able to complete this by leaving everything in a refrigerator. If you want to observe how the temperature fluctuates over several hours, power your setup with a battery and leave it running!

![Picture of calibration setup
here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/CalSetup.jpg)
Super high-tech calibration setup in a cold room.

Once you are certain that your calibration solution has been in a stable environment for some time, grab a calibration procedure and connect the MKRZero to your computer. Follow along with the calibration procedure step by step. It is important that you note the temperature of the solution to the nearest hundredth of a degree. You can do this with a separate temperature probe if you have one on hand, or you can assume that the temperature your CTD is recording is representative of the solution if the solution has been in the room for a few hours.

Conductivity is highly dependent on temperature, so it is important that you be as precise as possible! Using the provided spreadsheet or plots, take your calibration temperature and find the corresponding conductivity value to the nearest 100 uS/cm. You'll use these values in the calibration procedure. Don't forget to write down your calibration temperature (to the nearest hundredth), as it will later need to be manual input into the operating code.

In addition to temperature, conductivity of a solution also depends on the concentration of ions, the nature of the ions, and the viscosity of the solution. For our calibration application, we can consider these to be already known or negligible.

Here is a new [Google spreadsheet](https://docs.google.com/spreadsheets/d/1NTyalpajds06tLAo7uXbJdM82hv5m03zCGFynGOxZ1g/edit?usp=sharing) that will help determine the conductivity values to input for your calibration temperature.

After you have confirmed proper calibration of the probe, it won't need another calibration for a year. You can now cut the cable down to 6-8" in length. Please note that cutting the cable voids the Atlas-Scientific warranty, so it important to first test the probe to see if it works. After you have cut the cable, you can remove the protective cap (the one with the serial number on it) as it takes up unnecessary room in the pressure case.

Case Construction and Potting
Once everything checks out and your breadboard tests are successful, you can begin to put the pressure case together.

Tools	Protective Equipment
Plastic Cups	Eye Pro
Plastic Stir Rod	Nitrile Gloves
Sand Paper	Safety Mask
Tape
Round File
2mm Hex Wrench

Switch/Pressure End Cap

Designate one end cap and flange set as your switch/pressure sensor end cap and the other your conductivity/temperature end cap.

For each set, connect the two pieces together using the six M2 screws. Don't worry about installing the O-Ring just yet. Once connected, use sandpaper to prepare the inner surface of each flange and end cap set. Alternatively, use a marker to outline where the two pieces meet and sand accordingly. Abrasion of the surface will allow the urethane you will apply later to bond more readily to the metal surface. Use a low grit sandpaper to remove anodization until you begin to see bare aluminum. Try not to abrade the O-ring groove.

Here are some [videos](https://www.masterbond.com/resources/video-library?tid=354) on how to prepare a bonding surface.

The end caps that you have are blank and will need two holes drilled into them. Here are the [Blue Robotics drawings for the 2" end caps](http://docs.bluerobotics.com/assets/images/WTE/drawings/WTE2/WTE2-P-END-CAP-2-2X10MM-R1.png). Additional information can be found in the [Blue Robotics documentation](http://docs.bluerobotics.com/watertight-enclosures/).

Once you have drilled the two 10mm holes, on **one end cap per CTD**, one of the holes will need to be drilled out to 12mm to accomodate the EC probe.

![Picture of prepared end cap
here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/2.PNG)
Flange with the internal side abraded.

Remove the face plate from the flange. Use isopropyl alcohol to clean the surface thoroughly. Install the switch and pressure bulkheads, with O-rings, using the penetrator wrenches. Don't forget to abrade the inner bulkheads as well!

![Picture of installed bulkheads
here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/1.PNG)
Picture of the pressure and switch bulkheads installed.

Conductivity/Temperature End Cap

Do the same thing with the other end cap. After sufficient abrasion, install the temperature sensor in the end cap.

The conductivity sensor has too large a diameter for the pre-drilled holes, so you will need to drill out **one** of the holes to 12mm or 15/32". It may be a tight fit for the probe, so use a round file to make it the right size. Once you have the proper hole size, insert the probe so that it sticks out of the end cap approximately 2-3". To keep it in place, rig up a stand that will hold the probe in the right spot, or hot glue it into place from the outside. Tape over the probe hole to prevent any material from entering the sensing area.

After you have prepared each end cap, you can re-connect them to the flanges. Make sure everything is clean. Wrap the O-Ring grooves of the flange in tape to prevent any spillage getting into the grooves during the next step.

Applying the Urethane

The urethane you are using is called Urethane 75a. It is specifically designed for potting of electronics and cables that are placed in seawater. It is important to use plastic tools during mixing so as not to introduce moisture to the urethane. Using wood or paper mixing tools will upset the cure process.

![Picture of Urethane
here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/5.PNG)
Blurry picture of the urethane bottles.

The urethane should have come with a small packet detailing the best practices of use for the material. The most important things to do are to ensure that the surfaces the urethane will contact are sufficiently abraded and that there is no moisture. Moisture induces bubbles which ultimately weakens the waterproofing capabilities of the urethane.

Pour equal amounts of each urethane component into seperate cups. You should pour enough so that the combined amount is at least 3 oz. Using less may not be enough to generate the exothermic reaction needed for the curing process. Pour two components into one cup. Slowly mix with the stirring stick for two minutes and take care not to introduce bubbles. You will have five total minutes of working time. At around three minutes, the mixture will become thicker and more difficult to pour. Mixing too quickly can generate too much heat and reduce your overall working time.

Here are some [videos](https://www.masterbond.com/resources/video-library?tid=354) on how to mix and apply two part epoxies.

`![No Urethane](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/7.PNG)`
Conductivity and temperature sensors ready to be potted.

Pour the urethane into each end cap until it reaches the brim of the flange. Tap the edges of the flange with a clean plastic stir rod to shake up any bubbles attached to the walls.

Note that in some fashion the switch also acts as a purge plug. So you may only want to fill up to the bottom of the switch portion that you screw into the bulkhead.

![Picture of urethane and end caps
here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/6.PNG)
Poured urethane.

`![Pic2](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/4.PNG)`
Poured urethane.

Allow to cure for a minimum of 12 hours.

Completing the Circuit

Tools	Protective Equipment
Soldering Iron	Eye Pro
Hemostats	Nitrile Gloves
Wire Strippers
Third Hand

[Watch this video on the Lineman's Splice](https://www.youtube.com/watch?v=O-ymw7d_nYo)

While your end caps are curing, you can begin to solder the electrical components together. You'll want to arrange the RTC and EC EZO so that you can easily solder corresponding pins. You also want to minimize the width of the protoboard package. One thing to keep in mind is that you will want the SD card pointed in the direction of the switch/pressure end cap.

There are two options for soldering everything together. You can solder everything together with free wire, which may get a little messy but offers more flexibility in the tight pressure case. The other option is to place everything on a nifty MKRZero protoboard. Note that where you place the wires is up to you. You'll be placing the MKRZero on top of the protoboard so that the wiring is placed in between the two boards. **Double check to see if you are connecting pins correctly.**

`![a;lskdjfaf](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/RTCEZO2.jpg)`

First, desolder the female header pins on the MKRZero and solder on some male header pins as show in the picture below.

`![Male](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/MKRMale.jpg)`

When bridging two connections with a piece of wire, bend the wires 90 degrees at the tips so that they seat properly in the through holes. You will need to cut the wires to length in order to get them to bridge the right connections.

`![BendingWires](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/BendingWires.jpg)`

First start by placing the EC EZO and RTC on the protoboard, and solder the pins to the board. Next solder the RTC SS and MOSI pins to the corresponding MKRZero pins. Shown as bare wires at the bottom left of the picture below. Because it is also difficult to solder all the wires to a single GND and VCC pin, you can create a single point on the board where the can meet. As shown in the picture below, all ground wires will bridge to the top of the board, and all VCC wires will bridge to the bottom.

`![GNDVCC](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/VCCGND.jpg)`

Next, you can solder the RX and TX of the RTC to your TX and RX connections on the MKRZero.

`![ECEZOTXRX](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/SolderWires3.jpg)`

You can also solder the CLK and MOSI pins on the RTC to the respective MKRZero pins.

`![MOSISCK](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/SolderWires4.jpg)`

Once you have done that, you can solder the VCC and GND pins of the RTC to your GND and VCC connections. Once you have done that, cut the female end of the 6-pin connector down to about 1 inch in length. Insert the wires from the RTC side of the protoboard, and solder them into place. Next, bridge the two middle wires to the PRB pins on the EC EZO using a ton of solder. (As show on the left side of the picture below.

`![More](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/SolderWires2.jpg`

Here is an example of what your VCC and GND connections should look like.

`![Bus](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/Bus.jpg)`

Next, add the male 4-pin connector to the protoboard in a similar fashion as the 6 pin. In the picture below, you'll see that on the 4 pin connector side, the order goes SDA (white), SCL (green), GND, and VCC (from top to bottom). On the 4 pin side, you'll see that the order goes GND, VCC, PRB, PRB, SCL (green), and SDA (white). First, connect the VCC and GND wires of those connectors to the GND and VCC bus connections. Then solder the SDA and SCL connections of each connector to the respective MKRZero pin.

`![All](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/All_Soldered.jpg)`

There may be cases where you can't solder directly to the pin, so you may need to solder the wire to the closest throughhole. In that case, you can create a pool of solder that connects the two holes together as shown in the next couple of pictures.

!\[Pool](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/Solder_pool.jpg)

!\[Pool2](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/Solder_pool_2.jpg)

In this case, the pressure sensor will be connected to the 4-Pin JST connector located on the RTC side of the protoboard, and the temperature and conductivity probe will be connected to the 6-Pin JST connector located on the EC EZO side of the protoboard.

There is no set orientation for wiring everything up, nor is there a predetermined wire length for connections (although I recommend leaving about 6" of wire on the EC probe and temperature sensors). It is recommended that you test the connectivity of every connection to make sure you aren't creating any shorts. Make a note of which wire goes where, because after your urethane is done curing, you will want to make sure you have the right wires hooked up! Solder everything together as described by the pinout guide. If you want to avoid using a ton of heat shrink, you can use UY2 cold splice connectors. There is no specific orientation for the EC probe leads to the EC EZO. You'll want to make sure you are soldering corresponding wires for the JST connectors.

!\[JSTPressure](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/JST2Pressure.jpg)
An example of a JST connector on the pressure sensor.

!\[RTCEZO](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/RTCEZO2.jpg)
Everything set up facing the RTC and EC EZO.

In order to get everything to fit, I ended up trimming the header pins on each of the modules. Once you have them ordered, you can trim them to a length that works for you.

!\[MainZero](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/MainZero.jpg)
*Everything set up facing the MKRZero.

Switch Cable
In order to externally turn off the CTDizzle, we need to install a switch. It is not recommended that you cut the battery cables to install the switch, as this may have an impact on the charging of the battery. Instead, use a JST extension cable to tie the switch into.

First, cut the cable at the midpoint and trim each end so that about two inches remains on each side. Using a cold splice connector, reconnect the VCC (red) line. Then connect a switch lead (blue wires in the switch bag) to each of the ground leads using another two cold splice connectors.

!\[Picture of Switch cable here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/SwitchCable.jpg)
Example of a switch cable with cold splice connectors.

Final Case Construction

Tools	Protective Equipment
O-Ring Pick	Nitrile Gloves
Hemostats

The CTD is going to depths where pressure is roughly 200 psi. This pressure is experienced from all directions. The optimal shape for a pressure case would be spherical, but it is often difficult to fabricate spheres, so the next best option is to use a cylindrical case. If you have a spherical and a cylindrical case with the same wall thickness, the cylinder will typically have half the strength as the sphere. Cylindrical pressure cases are typically closed off by hemispherical (rounded) or torispherical (flat) end caps. We are using the Blue Robotics aluminum tube case for several main reasons, the compatibility of sensors, the ease of access, and the robustness of aluminum over acrylic.

Rectangular pressure cases, while much easier to manufacture, can't really withstand pressure as well as cylindrical cases. There are more failure points and the odd shape of the O-Rings increases the potential of more leak points. Force is being exerted on the pressure case in all directions, and with a rectangular case, there are more points where the case can fail as some areas are not as well supported (think corners vs. walls).

After recent developments, this CTD build is depth restricted to 200m. Atlas-Scientific has recently tested the conductivity probe down to 343m with success. Blue Robotics states that their temperature and pressure sensors can reach 500m without issue. The limiting factor for this CTD build is the mechanical switch used to turn the device on and off. The manufacturer states that the switch has been tested down to 200m without issue. However, the complete build has only been placed down to 80m. The effects of exceeding this limit are unknown and caution should be exercised.

After you have soldered everything and tested the data output, you can finish constructing the case.

1. Ensure the flanges are clean. Grease the flange O-rings for the conductivity/temp end cap and install them.
2. Install the conductivity/temp end cap into the tube, ensuring the 6pin JST is connected.
3. Sort the wires, board, and battery.
4. Connect the MKRZero to the battery via the JST extension. Ensure that the switch is off or removed.
5. Place a desiccant pack in the pressure case.
6. Connect your pressure sensor to the protoboard via the 4-pin JST. Connect the switch to the switch cable.
7. Pack the aluminum tube with some sort of packing material if there is some play in the internal wiring and components.
8. Turn on the device using the switch. Note that the MKRZero does not turn on the LEDs when using battery power.
9. Turn off the device. Pull the card and check to see if a file is created and data is being output.

`![MKRZeroOut](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/TopOpen.jpg)`

`![Picture of completed device here.](https://github.com/CTDizzle/CTDizzle/blob/master/MKRZero/Documentation/Images/Complete.jpg)`
The CTDizzle Mk4.

Congratulations, you just built a working CTD!

Corrosion and Wear
The screws used in the end caps are made of 316 SS and the main body of the unit is made of aluminum.
When two dissimilar metals interact in seawater, galvanic corrosion can occur. The metal on the lower end of the galvanic scale (aluminum in this case) will begin to corrode after an extended period of time. Cathodic protection is one method to mitigating the corrosion of the end caps. This can be done by installing an anode (commonly made of zinc).

For now, there isn't a way to connect an anode (mostly due to no one manufacturing a 2mm threaded zinc). It is important to make sure that deployments are short (few days at most) and that the device is washed with freshwater when recovered.

On a recent test, the gel capsule on the pressure sensor was found to be worn away, presumably from sediment movement. It is recommended that you place a piece of tape over the pressure sensor or some AquaShield grease in the hole.

Predeployment Procedure
The deployment plan of your OpenCTD plays a role in the sampling regime.
- If you plan to take profiles, it should be set to sample as frequently as possible. The loop section of your code should restart about once per second.
- If you plan to leave the OpenCTD in the same location for several hours or days, it should be set to sample less frequently, anywhere between one minute to fifteen minutes depending on the deployment length. For example, if you are going to leave it out for a few days, sampling once every five minutes might be the way to go.

To determine how long your battery will last, you need to take your battery mAh and divide it by your peak amperage. I've found that when all sensors are sampling, the draw is about 35 mA.

Deployment Procedure
The device should be fully assembled and the proper sampling regime selected prior to reaching the study site.
1. Confirm all sensors, plugs, bulkheads, and end caps are secure.
2. Remove any sensor covers on the conductivity, temperature, and pressure sensors.
3. Turn the external switch clockwise until it can turn no further. The unit should now turn ON.

If profiling with the unit, it is suggested that it be left in the top few meters of the water column for approximately five minutes to allow for equilibrium. Once ready to profile, bring the unit to just below the surface, and allow it to descend at a rate around 0.25 m/s (~1 fathom every 10 seconds). The unit is only capable of sampling at a maximum of 1 Hz, so the slower the descent the better.

If planning to leave the unit at a particular site for an extended period of time, it is recommended that the user ensure that the device is properly secured and **ON** prior to leaving the site.

Recovery Procedure
1. After recovering the unit, turn the main switch counter-clockwise for 1 full rotation. Do not turn it any further or you may risk introducing water to the internals.
2. Spray the unit down with fresh water if possible.
3. If biofouling has accrued on the device, carefully remove the tape used to protect the case. If tape was not used to prevent biofouling, carefully use a soft bristle brush or plastic paint scraper to remove any fouling on the case.

For the sensors, use a soft bristle toothbrush or sponge to remove any biofouling. **Do not use a brush on the conductivity probe head.** If biofouling in the EC probe sensing area is non-compliant, you can place the probe in a 5% HCl solution and then use cotton swabs to remove obstructions. You can also try using freshwater or canned-air.

4. Dry the device.
5. Replace all sensor caps.

If the unit is primarily used for profiling, the device is ready to go once the user decides to collect data again. If there is concern that the battery may be low, refer to the Battery Charging Procedure.

If another stationary deployment is planned, the battery will likely need to be charged or replaced. This requires the user to open up the device.

Battery Charging Procedure
1. Turn off the CTD.
2. Remove the switch/purge end cap.
3. Remove the main electronics board and disconnect the battery switch cable.
4. Plug the battery directly into the MKRZero or other LiPo charger if available.
5. Connect the MKRZero to your computer or compatible wall outlet.

The MKRZero has the ability to charge a single-cell lithium ion battery when connected to a computer or microUSB outlet adapter. Simply plug in the battery to the MKRZero and connect the unit to a computer via microUSB. An orange LED should appear, indicating that the battery is charging. Even though the battery has a built in overcharge and damage prevention circuit, it is important that you do not charge your battery for too long.

It is recommended that you do not charge the battery through the JST switch cable.

Data Download and Analysis

Accessing and Plotting the Data
Currently, the user is required to open the device and pull the microSD card to access the data. **Make sure the device is dry before continuing.** Take care when removing the end cap, as it is important to keep the O-rings clean.

1. Connect the microSD card to your computer using an adapter.
2. Transfer the RAWCTD files you are interested in to your computer. It may be necessary to open these to check for dates and times. One way to differentiate between actual data and a test file is the file size.
3. Save all the files on the SD card to a seperate folder on the SD card labeled "Old Data".
4. There are several methods to process and analyze the data...
  - Through the provided MATLAB script.
  - Through the provided R script.
  - Through the provided [Google spreadsheet](https://docs.google.com/spreadsheets/d/1aZhM47wCaqce_ChUhZ3tBHn-EBdLj1RdgtKbndEPGLw/edit#gid=0) (in progress).
  - Through your processing program of choice. RAWCTD files are comma-seperated.

5. Once you are finished looking at the data, delete the RAWCTD files in the main directory of the SD card. This keeps things from getting cluttered.

6. Reinstall the microSD card and end cap. If you think the O-rings look a little dirty, clean and apply silicone grease before continuing.

Downcast vs Upcast (For Profile Deployments)

For near real-time data, Sea-Bird recommends that you look at the data that is collected while the device is travelling down the water column (downcast). This is so that the body of an instrument does not inhibit the flow of water through the sensors or induce mixing that may result in misleading values. This assumes that you have left the device at the surface long enough for it to reach equilibrium with the surrounding water.

Pinouts

MKRZero I/O pins are only 3.3v tolerant.

DeadOn RTC	MKRZero
GND	GND
VCC	VCC
SQW	Not Applicable
CLK	9 (SCL)
MISO	10 (MISO)
MOSI	8 (MOSI)
SS	D7

SQW is not needed unless you want to implement an alarm function.

Board SD	MKRZero
CS	28

SD capabilities are native to this board. No soldering needed here. This pin is called out in the operating code.

TSYS01 Temperature Sensor	MKRZero
Red	VCC
Black	GND
Green	12 (SCL)
White	11 (SDA)

MS5837 Pressure Sensor	MKRZero
Red	VCC
Black	GND
Green	12 (SCL)
White	11 (SDA)

EC EZO	MKRZero
Tx	13
Rx	14
VCC	VCC
GND	GND

TX on one side connects to RX on the other. TX should never attach to TX.
If connecting VCC to VCC, the EC EZO may report undervoltage. Testing and calibration may need to be done seperately if this issue continues.

Atlas-Scientific EC K1.0 Probe	EC EZO
Red	PRB1
Black	PRB2

After you cut the EC probe cable, the lead to PRB orientation does not matter.

Here is a list of parts used to build the CTDizzle Mk4, their vendor location, and the approximate cost for each item. You can probably find them elsewhere for cheaper and in less quantity. Some items from this list will provide enough parts for multiple CTDs. Prices do not include shipping, but I've done my best to select as few of vendors as possible.

Please note that you can adapt the CTDizzle to use sensors and boards of your own choosing, but it is your responsibility to ensure that they are compatible. For example, if you are not concerned about size and want to implement a larger battery, you can use the 3" watertight enclosure, but be aware that you may need to drill your own holes or purchase a couple blank penetrators.

Parts List
Part	Vendor	Price	Note
[MKRZero](https://store.arduino.cc/usa/arduino-mkrzero)	Arduino USA	$21.90
[MKR ProtoShield](https://store.arduino.cc/usa/mkr-proto-shield)	Arduino USA	$6.99
[3.7V 2200mAh Li-Ion Battery](https://www.adafruit.com/product/1781)	Adafruit	$9.95	Last for about 60 hours if sampling at 1Hz
[Conductivity Kit 1.0](https://www.sparkfun.com/products/12908)	SparkFun	$195.71	Includes EC EZO, probe, and calibration solutions.
[Celsius Fast-Response Temp Sensor](https://www.bluerobotics.com/store/electronics/celsius-sensor-r1/)	Blue Robotics	$56	+/- 0.1 C accuracy
[Bar30 High-Res Depth Sensor](https://www.bluerobotics.com/store/electronics/bar30-sensor-r1/)	Blue Robotics	$68
[DeadOn RTC](https://www.sparkfun.com/products/10160)	SparkFun	$19.95	+/- 2 min drift per year
[12mm Coin Cell](https://www.sparkfun.com/products/337)	Sparkfun	$1.95	Needs to be replaced annually.
[MicroSD Card with Adapter](https://www.sparkfun.com/products/11609)	SparkFun	$13.95
[2" Water Tight Enclosure Kit - 6"](https://www.bluerobotics.com/store/watertight-enclosures/wte2-asm-r1/#configuration)	Blue Robotics	$111	Select the 6" aluminum main tube, two flanges, and two aluminum end caps with the two holes pre-drilled. Includes o-rings and screws.
[Water Tight Enclosure Switch](http://www.bluerobotics.com/store/electronics/switch-10-5a-r1/)	Blue Robotics	$14
[Snappable Protoboard](https://www.sparkfun.com/products/13268)	SparkFun	$7.95
[4-Pin JST SM Plug Set](https://www.adafruit.com/product/578)	adafruit	$1.50	Allows removal of protoboard from unit.
[6-Pin JST SM Plug Set](https://www.adafruit.com/product/1665)	adafruit	$1.50	Allows removal of protoboard from unit.
[JST-PH Battery Extension Cable](https://www.adafruit.com/product/1131)	adafruit	$1.95	Allow easy use of external switch.

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|[Cold Splice
Connectors](https://www.adafruit.com/product/1496)|Adafruit|$2.95|Reduces
need for pesky heat shrink.


#### Consumables List
|Item|Vendor|Price|Note|
|:---|:---|:---|:---|
|[Breakaway Header - Straight
(x2)](https://www.sparkfun.com/products/116)|SparkFun|$3.00|
|[Loctite Marine Epoxy](https://www.amazon.com/Loctite-Marine-0-85-Fluid-
Syringe-1405604/dp/B00KH62K50/ref=sr_1_2?ie=UTF8&qid=1514606377&sr=8-
2&keywords=loctite+waterproof)|Amazon|$4.99|You will need about one per end
cap if building the 2" version. Buy three just in case.
|[Assorted 22 AWG - Solid Core
Wire](https://www.sparkfun.com/products/11367)|SparkFun|$16.95|
|[Heat Shrink Kit](https://www.sparkfun.com/products/9353)|SparkFun|$7.95|
|[Kester 44 Solder 0.8mm](https://www.amazon.com/Kester-Rosin-Core-Solder-
Spool/dp/B00068IJWC/ref=sr_1_4?ie=UTF8&qid=1496867514&sr=8-
4&keywords=kester+44)|Amazon|$33.43|1 lb of solder. Not necessary unless you
want to solder more than the OpenCTD.
|[Desiccant Packs (10g)](https://www.amazon.com/Desiccant-Indicating-
Chloride-Moisture-
Absorbent/dp/B01MPYB16J/ref=sr_1_1?s=hi&ie=UTF8&qid=1496867597&sr=1-
1&keywords=10g+desiccant)|Amazon|$8.99|Plenty of replacements.
|Masking Tape|
|Sandpaper|
|Black Tape|
|70% Isopropyl Alcohol|
|Kimwipes|



#### Tools List
|Tool|Note|
|:---|:---|
|Needle Hemostats|Flat edges minimize marring of items.|
|2mm Hex Wrench|Used for end cap installation/removal|
|Solder Station|The XYTronic 258 is a decent starter solder tool.
|Multimeter|Not necessary, but useful for checking connectivity and current.
|Breadboard|
|Jumper Wires|
|Wire Stripper|Capable of stripping 20-26 gauge wire.
|Drill or Mill|
|Drillbit - 15/32" or 12mm|Size for Atlas Scientific EC Probe|
|microUSB Cable|Data-capable Android phone charger works too.|
|Round File|Used to size drilled hole.|



#### Not Necessary But Helpful Items
|Item|Vendor|Price|Note|
|:---|:---|:---|:---|
|[Potting Kit](http://www.bluerobotics.com/store/tools/tool-potting-kit-
r1/)|Blue Robotics|$10|Keeps epoxy mess to a minimum.
|[Third Hand](https://www.sparkfun.com/products/9317)|SparkFun|$9.95|
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|[O-Ring Pick](http://www.bluerobotics.com/store/tools/tool-o-ring-pick-
r1/)|Blue Robotics|$4|They sometimes send you one for free if you buy a bunch
of stuff.
|[Penetrator Wrench](http://www.bluerobotics.com/store/tools/tool-penetrator-
wrench-r1/)|Blue Robotics|$12|
|[Calibration Solution K1.0 Set](https://www.atlas-
scientific.com/product_pages/chemicals/ec-1_0.html)|Atlas-
Scientific|$11|Already included in K1.0 kit, but it doesn't hurt to have
extra on hand.|
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