Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45363

Mapping Coastal Estuaries: Design and Validation of Drifter Buoys for Aquaculture and Climate Research

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Mapping Coastal Estuaries: Design of Drifter Buoys for Aquaculture and Research in Maine.

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Abstract

The Ocean Remote Sensing Program (ORSP) seeks to engage grade 9-12 and undergraduate students in ocean engineering skills to support Maine's ocean industries. The Gulf of Maine is recognized as one of the world's fastest warming bodies of water causing a sea change of challenges to Maine's coastal aquaculture industries and local communities. The increasing coastal water temperatures disrupt local marine ecosystems and alters coastal currents. These evolving challenges are increasing the complexity of grow and harvest operations necessitating improved coastal water monitoring programs to deliver real-time, hyper-local data to inform business decisions and improve science initiatives. Simultaneously, demand for ocean and marine engineers to develop and maintain new technologies in aquaculture, sea floor mining, offshore energy, transportation and ocean science is outpacing current graduation rates. In this work, we detail the methods and outcomes of the ORSP program and highlight the engineering outcomes of a team of eleven engineering student participants. The program participants include STEM-track undergraduate and high school interns tasked with the development, design and deployment of low-cost ocean drifter buoys. This experiential program seeks to address workforce development preparedness needs while enabling real-time water quality data to support local aquaculture industries in Maine. Participants are provided learning opportunities in manufacturing, electronics, programming, computer-aided design and the engineering design process. The drifters developed herein use low-cost Arduino-based microcontrollers and sensors to allow the acquisition of latitude, longitude, drift rate, drift direction, sub-surface temperature, turbidity and dissolved oxygen searchable by aquaculture companies in the region. Students participating in the project were surveyed to quantitate their engineering skills development and future interest in ocean engineering careers. The program successfully demonstrates improvement in ocean industry awareness, ocean engineering mission planning and ocean hardware operation and electronics.

Introduction

Maine’s Changing Aquaculture Landscape

Maine’s aquaculture industries are internationally recognized for quality attributed to its unique geography, ocean currents and climate. The Gulf of Maine is one of the richest marine ecosystems in the world and boasts harvests of Atlantic salmon, sea vegetables (kelp, algae, etc.) and shellfish (mussels, oysters, etc.), among others, and yields over $137 million of annual economic output to Maine’s economy.[1] Aquaculture is also the fastest growing food production sector globally, expected to increase by 5.5% annually through 2032.[2]

Maine’s aquaculture harvest, however, is uniquely susceptible to accelerating stressors due to climate change. The Gulf of Maine is warming faster than almost any other ocean body on the planet. The Gulf of Maine has averaged temperature increases of 0.86°F per decade since the 1980’s, nearly three times the global average.[3] Increased ocean temperatures are threatening local ecosystems by increasing competition by invasive species, migration of local species to cooler water, and changing currents within Maine’s coastal estuaries which alters reproduction patterns.[4] The impact of climate change on the aquaculture industry is an important area of scientific research with numerous National, State and local programs aiming to predict impacts and increase resiliency in the region. For example, the Maine Aquaculture Hub, A National Oceanographic and Atmospheric Administration (NOAA) SeaGrant research and industry network identified the need for increased research, workforce development and community outreach to help build a sustainable aquaculture base through 2032.[5]

In the near term, regional aquaculture businesses are struggling to adapt to the rapidly changing ocean currents and temperatures. The Casco Bay Region, home to the University of Southern Maine and a designated “estuary of national significance” by the U.S. Environmental Protection Agency (EPA), is the economic hub for Southern Maine supporting tourism, aquaculture and working waterfront facilities. The Casco Bay Estuary Partnership (CBEP), an EPA established National Estuary Program organization, have highlighted the need for increased water quality monitoring to quantitate hyper-local water temperature trends, decreasing dissolved oxygen and increasing impacts due to storms.[6] These data will support sustainable aquaculture by providing predictive forecasting of hyper-local water quality, nutrients loading and bio-organism density to allow better business decisions on location, timing and crop selection to optimize quality and harvest yield. Currently, this oceanographic data is generated and maintained primarily by State agencies who collect water samples up and down the Maine coast daily for manual water testing, in addition to a limited number of stationary buoys.

The Need for Workforce Development

Despite this data collection effort, local fisheries are generally limited to weekly average water condition data from many miles outside of their designated aquaculture zones. As a result, many aquaculture farmers conduct their own hyper-local water quality testing. Aquaculture companies are increasingly hiring ocean engineers and partnering with ocean engineering firms to procure and maintain hardware and manage oceanic data. There are currently 700 limited purpose aquaculture (LPA) licenses and approximately 150 licensed marine farms in Maine.[7] The sharp increase in the number of aquaculture operations in Maine has seen their economic output nearly triple since 2007.[8] Currently, scientific research and engineering/maintenance account for approximately 13% of the total aquaculture workforce in Maine with technicians accounting for 49%.[9] Therefore, the technical trades in Maine's aquaculture equate to almost two-thirds of the total workforce, or about 434 jobs. Extrapolating these job figures to the total U.S. aquaculture industry estimates that skilled science and technician workers total approximately 13,640.[10] Given this growing demand, along with increased ocean engineering production in offshore energy production and transportation, the U.S. Bureau of Labor Statistics anticipates employment for ocean engineers will increase at an 8% annual rate through 2033.[11]

Ocean Remote Sensing Program using Drifter Buoys

To address the growing demand for water quality monitoring and skilled ocean engineering professionals in the region, we have established a research program called the Ocean Remote Sensing Program (ORSP). The program seeks to benefit aquaculture industries in Maine by building industry awareness and engineering skills of young STEM learners to compete in the growing ocean engineering workforce. The program utilizes a hands-on immersive, experiential learning platform where students are provided STEM skills training within an objective-based design environment. The goal within the program is to design, manufacture and operate a fleet of low-cost drifter buoys to provide real-time, hyper-local, oceanographic data to local stakeholders.

Drifter buoys have a long history of providing ocean current data used in mapping, climate model predictions and ocean science.[12] These devices are used for the determination of ocean current heading and speed using global positioning system (GPS) technology, but they can also be outfitted with an array of water quality sensors specific to the mission requirements. Data gathered from these devices have supported a range of scientific endeavors including marine weather forecasting [13], climate change research [14], and marine pollution transport.[15]

Educational Objectives of the Ocean Remote Sensing Program

The program's educational objectives are to 1) build awareness of ocean engineering careers within Maine's student populations, 2) strengthen the student's desire to enter ocean industry careers, and 3) advance student engineering skills necessary for career advancement within the ocean industry. The objectives will be assessed using survey responses pre- and post-participation to quantitate student perceptions of their understanding of specific skills and career options. Further, the program tasks high-school interns and collegiate engineering undergraduates with 1) understanding the needs of the local aquaculture water quality monitoring and 2) develop low-cost ocean drifter buoys addressing the concerns. This manuscript provides details of the program methods employed in the creation of ocean drifter buoys and provide an assessment of the program's outcomes using student survey data.

Methods

The ocean remote sensing program seeks to be an immersive, hands-on, experiential learning opportunity for early career engineering students by providing them an objective-based design team environment. Students are taught engineering theory such as basic electronics, manufacturing, engineering design, communications and elements of ocean engineering. Students are also taught basic hands-on skills such as computer-aided design, soldering, wiring, hand-tool operation, basic machining and computer programming. Student are assessed on their perceptions on skills development and overall attitudes towards ocean engineering. This section provides an overview of the student population and the program operations.

Student Recruitment

Students were recruited in two ways; the first method included internal job postings at the university to recruit engineering undergraduate students. The second was to participate in the Maine Space Grant Consortium (MSGC) MERIT scholar program to host exceptional high school students in summer internships. In total, seven collegiate engineering undergraduates and four high school interns participated in the program. No previous experience in ocean engineering or boatmanship was required. Recruitment for the program started in 2023 with two collegiate students and one high school intern. The program was expanded in 2024 with five additional collegiate students and three high school interns. The high school summer interns participated for 10 consecutive weeks, while collegiate students worked between 2-10 hours per week during the academic year.

Student Demographics

The seven collegiate students consisted of four mechanical engineering students and two electrical engineering students with one student enrolled as a double major in mechanical and electrical engineering. The collegiate students also ranged in academic preparation with one freshman, three sophomores and two juniors. The collegiate students identified as 4 males and 3 females. The high school interns were matched based on their responses to a questionnaire administrated by MSGC which ranks learning interests across multiple disciplines including computer science, engineering, biology, etc, on a 0-3 scale. Students were also able to rate their perceived strengths and weaknesses across multiple skills sets including computer aided design, programming, communication, etc. All interns expressed “very interested - 3” interest in engineering, but with varying levels of interest in ocean science ranging from “very interested - 3” to “somewhat interested -1”. The resulting interns were three male and one female. All interns had completed their junior year except for one sophomore student.

Student Pre-Participation Survey

A pre-participation survey was administered to the students using a four-level Likert scale to assess preparation, STEM interest, and likely career path. A summary of questions and responses is provided in Table I. All participants responded to the survey (n = 11). The survey questions were reviewed, selected and approved by the research team to ensure compliance and specificity. The survey was tested for validity by critical value testing using a Pearson’s correlation coefficient at 95% confidence interval. All question, apart from questions 7 and 10, obtained a correlation above the critical value, 0.5214, for single tail multivariate distribution with 9 degrees of freedom. Interestingly, Questions 7 and 10 both inquire about the participant's understanding of ocean engineering and the environment and not general engineering skills or knowledge. Question 1 presented a very strong response with an average of 3.91-out-of-4, which is expected given the population of high-achieving college-bound high school interns and engineering undergraduate students. Yet, respondents also report being "unsure" or "not confident" when asked about confidence in basic electronics and programming. These results were consistent across both male and female respondents as well as education level.

Table I: Participant pre-participation survey questions and responses (n = 11)

Q#	Question	Result* (Ave.)
1	How likely are you to pursue a career in STEM?	3.91
2	How likely are you to pursue a career in the ocean industry?	2.45
3	How well prepared do you feel to participate in an ocean engineering project?	2.64
4	How confident are you in describing a drifter buoy to a peer?	2.64
5	How confident are you in explaining the engineering design process to a peer?	2.82
6	How confident are you in explaining the primary components of a buoy to a peer?	2.00
7	How confident are you in explaining ocean industry career options to a peer?	2.09
8	How confident are you in explaining project management principles to a peer?	2.82
9	How confident are you in explaining ocean device mission planning to a peer?	2.36
10	How confident are you in explaining the ocean environment to a peer?	2.36
11	How confident are you in explaining the operation of basic sensors to a peer?	2.72
12	How confident are you in explaining computer aided design to a peer?	2.82
13	How confident are you in explaining basic computer programming to a peer?	2.54
14	How confident are you in explaining basic electronics and wiring to a peer?	2.45

*1 = unlikely/poor, 4 = very likely/very confident

Stakeholder Input

The student design team engaged with community stakeholders including scientists, aquaculture companies, non-profits and State organizations through a combination of guest lectures, conference meetings and one-on-one discussions. In total, the students gathered information from 15 working professionals representing nine organizations with a presence in Casco Bay. These included three non-profits, three for-profits, two organizations of higher education and one State government agency. These communications bolstered student awareness of ocean industry concerns and focused the design efforts. The following design criteria were developed by the students.

<u>Increased spatial resolution of water quality and current data:</u> There currently are no drifter buoys routinely providing publicly available data within the estuary. Existing data is limited to stationary buoys and manual water sampling which provides high accuracy data with poor spatial resolution. Suggested drifter buoy data includes:

- Time-resolved location
- Current speed
- Current heading
- Surface water temperature
- Subsurface water temperature
- Dissolved oxygen
- Salinity
- Turbidity
- Nitrogen and phosphorus loading
- Watercolor

Low capital and maintenance costs: The majority of stakeholders are small, independent, companies or organizations requiring affordable access to data and hardware. Although affordable is an ambiguous term, it was generally acknowledged that a unit cost of $250-$1,000 per monitoring device was acceptable. The devices also needed to have minimal maintenance and can be deployed by technician-level employees. Data should be archived to a web-application dashboard for easy visualization.

Trade-off between local precision and spatial resolution: It was generally acknowledged that a trade-off between spatial resolution of data in Casco Bay and cost exists. For example, an increase the number of devices gathering data, requires additional costs of manufacturing and operations. To optimize this trade-off, it is acceptable to decrease the precision of measurements on individual buoys to reduce unit costs. This approach takes advantage of existing high precision data being gathered at stationary buoys and completing the gaps with low-precision instrumentation.

Serviceable Lifetime: The service lifetime of the drifters is desired to be at least 3 years. This approach requires that the drifters be recoverable and not allowed to exit the bay to open waters. It is desirable to establish an automated way to seek and retrieve drifters using autonomous vehicles over manual recovery. This trade-off would require high capital costs and development timelines versus high maintenance costs for manual retrieval.

Constraints and Specifications

Careful review of the stakeholder requirements using quality functional deployment (QFD) methods led to the engineering design constraints tabulated in Table A1 in the appendix. Critical performance features were identified to be long operational lifetime (~5 years) with a per unit cost less than $300 and minimal maintenance. A GPS unit capable of determining spatial resolution to within +/- 3 m with an update rate of a minimum of 0.2 Hz was a high priority. It is also highly desirable to utilize the GPS unit to acquire ocean current heading and speed at high resolution. The only other required sensor was temperature which is required to have high resolution (+/- 0.25°C). Together ocean current and temperature data at sufficient spatial-temporal resolution was considered a priority by the team, while other sensors, such as dissolved oxygen, watercolor, turbidity, etc. were desirable, but must be balanced with unit cost and maintenance requirements.

Engineering Design Process

The student design team was provided guidance and instruction in the engineering design process through one-on-one instruction and lecture materials developed at the University as part of engineering design courses. The students were instructed to develop system architecture to meet performance and cost specifications followed by hardware form factor and layout.

Students were divided into small groups during the design effort using R.A.C.I. roles and responsibilities protocols. Each student was assigned as a principal engineer on primary buoy components, such as hardware, programming/logic, sensor development, etc. The students worked in a common workspace and were provided weekly 1-hr team meetings to discuss individual and team progress. Each student presented their work to their peers and received feedback from faculty and staff. Engineering work was archived to a GitHub exchange where the team members could see individual and team progress.

To begin, each student was provided common training on basic machining, programming, soldering, dc wiring, electronics, and computer-aided design. Basic machining included students creating name plates out of aluminum using a Bridgeport mill as well as basic hand tool safety training. OnShape, web-based CAD software, was chosen given the extensive free online learning modules training and ability to cloud share designs. Electronics and soldering training utilized a leaning kit of a soldering breadboard and basic LED power circuit. Student training was assessed for proficiency and safety by university faculty and staff. Basic training took about 3 weeks and catapulted students into their design efforts. The following section briefly describes the students' design considerations and the resulting drifter buoy devices.

Drifter Buoy Architecture Selections

Programmable Development Board. System architecture was selected primarily based on cost, but with consideration for availability of existing resources as well as size and weight. An Arduino-based computer architecture was selected in favor of low power consumption and weight to achieve >24 h continuous operating requirement between recharges. The Arduino Mega development board was selected for prototype purposes given the increased capacity and dual serial communication ports.

Power System. The team opted for rechargeable lithium-ion batteries. The drifter buoys are intended to operate within the 229 square miles of Casco Bay and will require frequent retrievals and redeployments. This unavoidable operational constraint allows for routine access for battery recharging allowing the prototype to forgo the cost and complexity of solar panels.

Sensor Selection. Numerous sensors were evaluated, the details of which are too voluminous to fully describe herein. In summary, a market survey was conducted for each measurement required in the performance specifications listed in Table A2 in the appendix. The sensors were then scored using a weighted scoring system involving cost, power consumption, Arduino compatibility, sea water compatibility, measurement range, measurement resolution, durability and ocean heritage. The highest scoring sensors are provided in Table II. Unfortunately, no salinity or nutrient loading (nitrogen and phosphors) sensors were acceptable for the application.

Table II: Drifter buoy sensor list developed using weighted down selection process.

Measurement	Manufacturer	Model	Comms	Power	Range	Resolution
Temperature	Adafruit	MCP9600	I2C	0.5 mA @ 5V	-200°C to 1372°C	0.0625°C
Turbidity	DF Robot	Gravity	Analog	40 mA @ 5 V	0-4000 NTU	20 NTU
Location/ Current speed	Seeed Studio	Air530	UART	60 mA @ 5 V	unlimited	2.5 m
Dissolved Oxygen	DF Robot	Gravity DO kit	Analog	N/A	0-20 mg/L	0.02 mg/L
Color	Seeed Studio	VEML6040	I2C	0.2 mA @ 5V	16496 Lux	0.008 Lux
Salinity	None Found					
Nutrient Loading	None Found					

Data Communication. Although the design team has experience with both radio and cellular communications, ultimately it was decided to utilize onboard storage and retrieval. This approach takes advantage of the high frequency of buoy retrievals and redeployments to further reduce costs and complexity of the design. An inexpensive microSD breakout onboard data storage device can be easily accessible to operators for rapid retrieval. A 64x128 pixel OLED screen will provide visual indicators of system health, sensor performance and GPS connectivity. A LandAirSea 54 GPS tracker is used for live position tracking and retrieval.

Hardware and Form Factor

The material of construction and form factor provide the first line of defense to the ocean elements and serve as critical support surfaces for sensor mounting. Stakeholder specifications put a premium on low unit costs, durability, serviceability and low maintenance costs. These constraints necessitate the use of off-the-shelf components made from low-cost construction materials. The team identified two possible solutions. The first is 4" polyvinyl chloride (PVC) schedule 40 piping. This type of piping is cylindrical, waterproof and comes in a wide variety of configurations. The second material is 3" square cross-section extruded aluminum tube. This tubing comes in different wall thicknesses and is readily available from commercial suppliers. Aluminum is infinitely recyclable, offers good corrosion resistance when anodized, and exhibits high strength and impact durability which aids long operational lifetimes. The drawback with aluminum construction is the need for skilled laborers to machine and weld unions together.

The form factor of the drifter is expected to be long in the vertical axis. The main drifter buoy is expected to have approximately 6-12 inches of vertical height above the water line with a clear top to help with GPS communications and provide visual information to the user. The drifter buoy body is anticipated to be approximately 3 ft. below the water line. The buoys are expected to operate vertically within the water column and accommodate sensor placements within the ocean surface and subsurface environments.

Results and Discussion

Drifter Buoy Designs

Initial Drifter Buoy Design – GPS and Temperature: The initial buoy prototypes were constructed using 4” schedule 40 PVC pipe as shown in Figure 1. The design incorporates an Arduino Mega powered by two 500 mAh 9V rechargeable batteries. The Arduino and associated electronics are mounted to a 3D printed electronics chassis which are inserted into the piping. Sensors on the initial prototype include an Air 530 GPS module and two MCP9600 thermocouple digital amplifier boards located at 6” and 36” below the water line. The thermocouple probes were both type K with 6” long, ¼” OD stainless steel sheaths. The thermocouple probes were secured to the drifter housing using threaded aluminum cord grips mounted onto flat PVC end caps affixed to 4” PVC tee unions. The GPS unit was mounted within a waterproof polycarbonate electronics enclosure that was secured to the top of the drifter using Loctite 5200 marine grade sealant.

Lead shot pellets (11.3 kg) were installed into the base of the drifter as ballast to keep the drifter vertical in the water column. A microSD breakout board was used as data storage and had a 0.96” OLED screen for local data communication. Data was gathered at a rate of 0.2 Hz using the Arduino internal clock and synchronized using the GPS timestamp. The entire assembly was waterproofed using PVC glue and then pressure tested for leaks to 8 psia. Leaks were sealed using JB weld or PVC glue as necessary.

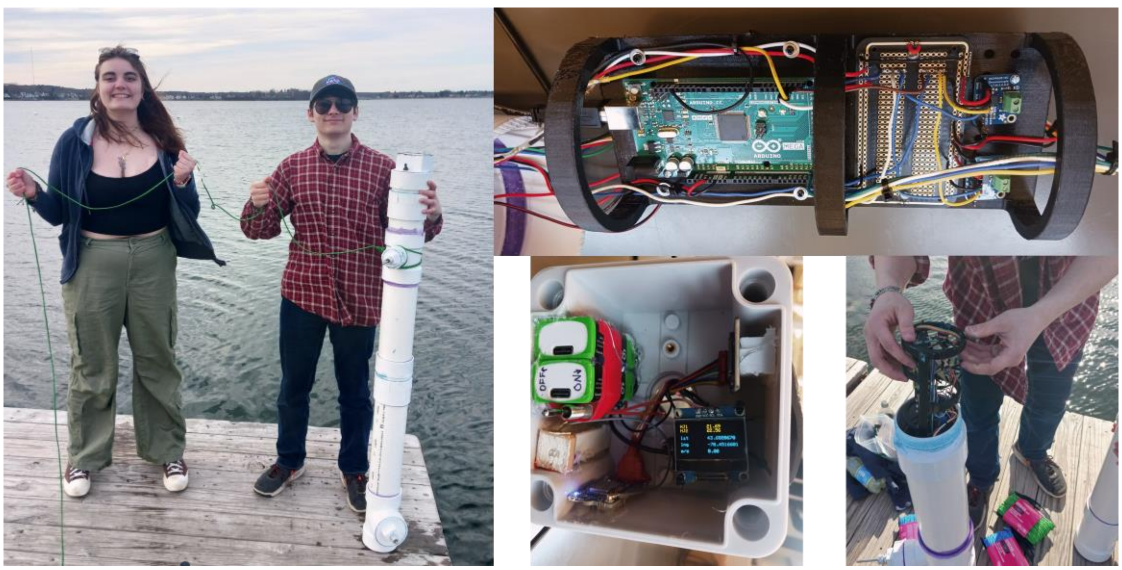

Figure 1: Photographs of initial drifter buoy design incorporating dual temperature and GPS measurements

After successful dock testing, two additional drifters were constructed by the students in the summer of 2024 utilizing identical construction and electronic packages except for two 1300 mAh 9V batteries for increased operational time. Laboratory testing of the battery packs confirmed a 30+ hour operational window when fully charged. Fiberglass rods, (1/4” OD x 24” long) were also affixed to the drifter external structure using 4” stainless steel band clamps to support a high visibility buoy flags for boater safety. Total cost of the prototype drifter was $517 per unit with most of the cost, $231, going towards electronic components, including the Arduino, sensor boards, thermocouples and memory storage. Hardware costs for PVC and pipe adapters were an additional $244 per unit. The remining costs were associated with wire, epoxy, sealants, and miscellaneous consumables. The drifter buoys were tested in Casco Bay in July 2024 as shown in Figure 2. The drifter buoys were released initially for an 8 h period. The retrieved data was imported into Google Earth for visualization as shown in Figure 3. The visualized data contains periods of boat transportation as well as periods of ocean drifting. Data is organized as temporal latitude and longitude coordinates with metadata containing current and temperature information.

Figure 2: Photographs of the first successful drifter buoy launch into Casco Bay in the summer of 2024.

Figure 3: Visualization of buoy data obtained in Casco Bay – summer 2024.

Drifter Buoy V2 – Incorporating Turbidity and Dissolved Oxygen: A second drifter buoy version (V2) was developed incorporating the DF Robot Gravity turbidity and dissolved oxygen sensors. To balance costs associated with the additional sensors, the students decided to discard the subsurface thermocouple. A full breakdown of the drifter cost by component is listed in Table A2 of the appendix. A schematic of the final V2 drifter design is shown in Figure 4. The new drifter is 29" long and utilizes a 3-D printed electronics chassis (right). User access is provided for the GPS, OLED screen, 9V battery bank, LandAirSea 54 tracker and microSD card breakout board which are all located in a polycarbonate washdown electronics enclosure mounted to the top of the drifter housing. As with the initial prototype, the V2 design does not incorporate underwater sail components. This choice was based largely on results of the initial drifter and those of Novelli et al., which suggests that intercoastal drifters are much less likely to become beached at a modest expense with current drift accuracy.[15]

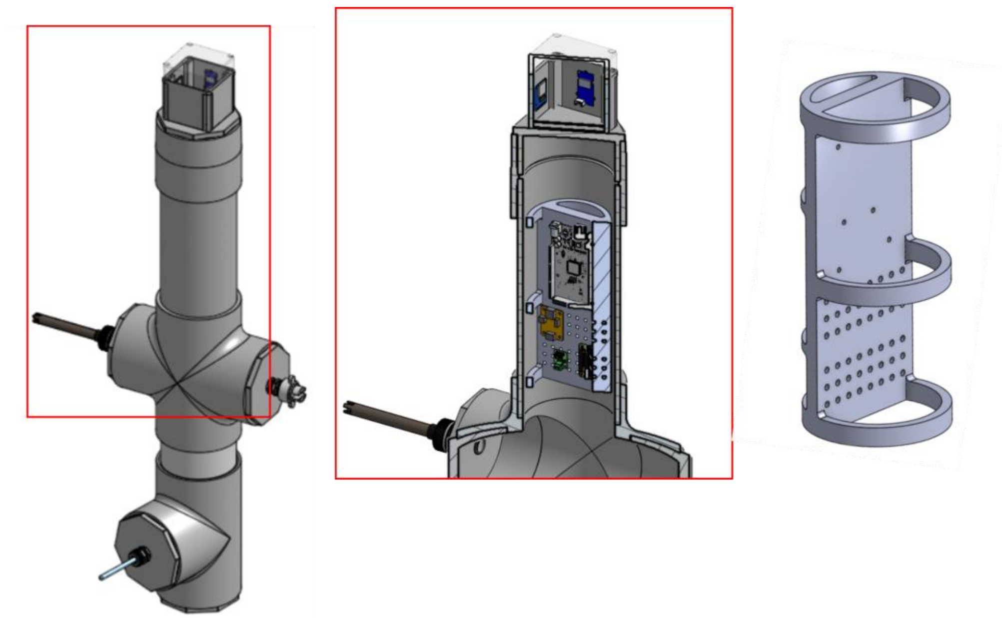

Figure 4: Drifter buoy V2 CAD design incorporating dissolved oxygen, turbidity, GPS and temperature measurements.

The bank of four 1300 mAh 9V batteries provided 27 hours of continuous operation which met the >23 h operational requirement. A wiring diagram detailing the Arduino connections is provided in Figure 5. All sensors and extension boards were directly supported by the Arduino's internal power regulator. The OLED and MCP9600 thermocouple amplifier board each use I2C communication while the GPS Air 530 sensor is directly connected via UART ports. The microSD card reader utilized MOSI/MISO digital communication protocols. The turbidity and dissolved oxygen sensors are analog devices calibrated using a single-point internal calibration.

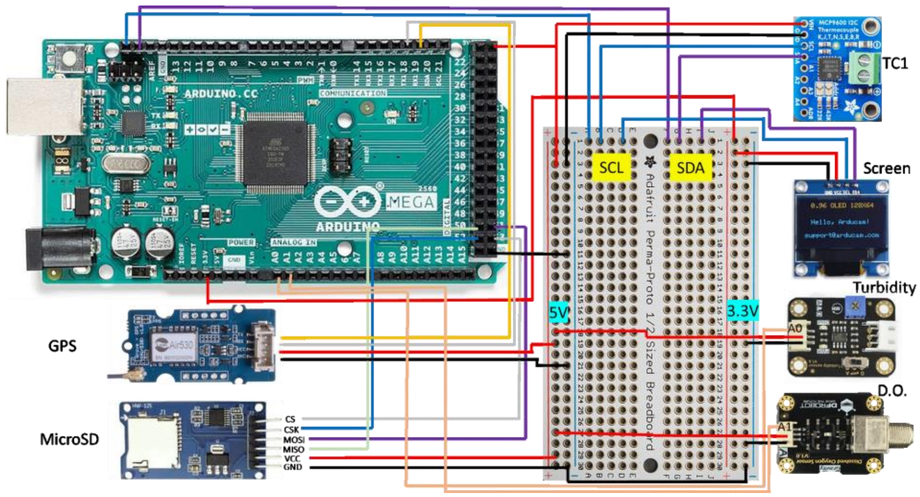

Figure 5: Wiring diagram of drifter buoy V2 detailing sensor connections and power distribution.

Drifter Buoy V3 – Aluminum Housing: The final drifter design is a modification of the V2 incorporating a fully-aluminum exterior. This design utilizes 3" square cross-section aluminum with a wall thickness of 1/8". The aluminum housing utilizes welded aluminum top and bottom plates as well as a 6" long x 3" wide panel cutout for electronics access as indicated in Figure 6. A square cross section electronics chassis (right) was designed to accommodate both Arduino Mega and Raspberry Pi development boards. GPS and OLED screen access is again provided using a polycarbonate washdown electronics enclosure suspended above the main drifter body.

The structural aluminum frame not only increased the drifter durability compared to PVC piping, but it is also significantly cheaper. As shown in cost breakdown of drifter design V2 in Table A1, the PVC housing materials cost approximately $205 despite being off-the-shelf components. The structural aluminum was purchased from a local materials supplier at a cost of $16 per foot. Therefore, this design could accommodate a full 36" water depth drifter buoy for a housing cost of approximately $50 equating to a 400% savings in housing materials. The V3 design will also be outfitted with 1 ft. by 2 ft. ripstop nylon sails for more accurate current drift data.

Data Storage and Visualization

Data storage and visualization is completed using a project landing page at the University's website. A screen shot of the draft website functionality is shown in Figure 7. The website is expected to be organized by drifter, with each drifter given a unique identifier information. A historical record of each drifter's operations will be available to operators and stakeholders. Historical events include maintenance intervals, calibrations results, deployments and modifications. Each deployment will be archived and searchable by date or location using dropdown menus. Once a particular deployment event is highlighted, an embedded Google MyMaps widget will display interactive data for users to browse as shown in the right image of Figure 7. Once the user selects a data point of interest, metadata including sensor information, date and time are displayed to the user in a data table.

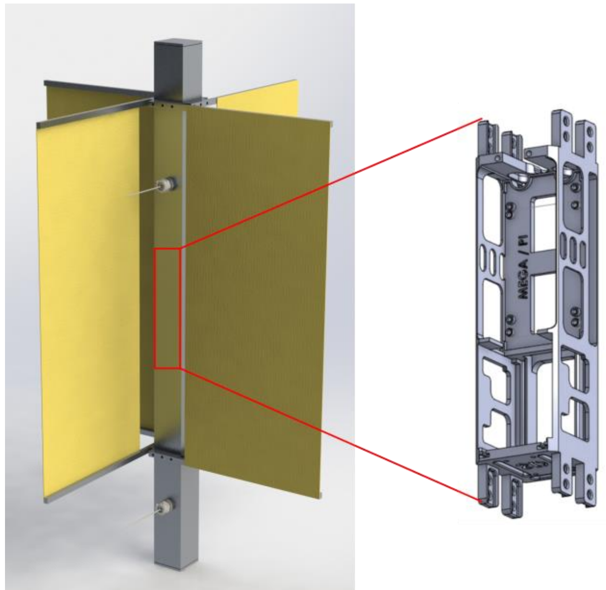

Figure 6: Rendering of drifter buoy V3 with 3” square aluminum, sails and electronics chassis.

Raw data archiving will be accomplished using a GitHub project page. The page will also contain detailed information on drifter design, construction, sensor wiring and programming to enable stakeholders and the public access to our methods and data. GitHub data will be organized in two methods, location and date such that data users can quickly find data of regional significance for their research. Data will be made available via .csv and .kml file formats enabling spreadsheet analysis and visualization using GPS compatible protocols.

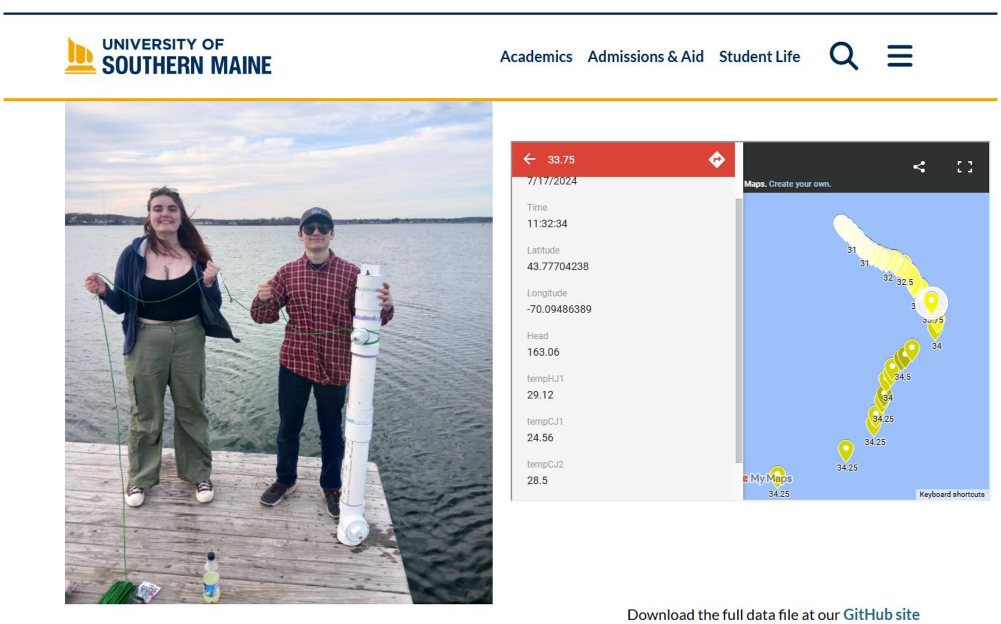

Figure 7: Screen capture of project website detailing searchable drifter data.

Program Learning Outcomes Assessment

A post-participation surveys was given to the participants at the conclusion of the project that was identical to the pre-participation to assess student perceptions on engineering skills and industry awareness. The project is shown to be an effective tool to improve student confidence in ocean engineering and was successful in building awareness of ocean science. A chart showing the percent change in participant responses to the survey questions described in Table IV is presented in Figure 8. The strongest modification was seen in Questions 4, 6, 7 and 9 which tested participant understanding of drifter buoy engineering and operation. Students who participated in the project initially reported feeling "not confident" and later indicated a "confident" or "very confident" rating in the post-participation survey.

Results were tested for significance using a two-tailed Mann-Whitney U test at a significance level of 0.05. Results showed that only questions 4, 6, 7, 9, 10 and 14 exhibited statistically significant differences in student confidence pre- and post-participation. This result indicates that project participation was successful in improving student confidence in ocean engineering and drifter buoy engineering and operation. The data is not conclusive in improving the desire to enter careers in ocean engineering, despite the positive response rates. It is anticipated that broadening participation in the project to a larger student population may improve the significance of the results.

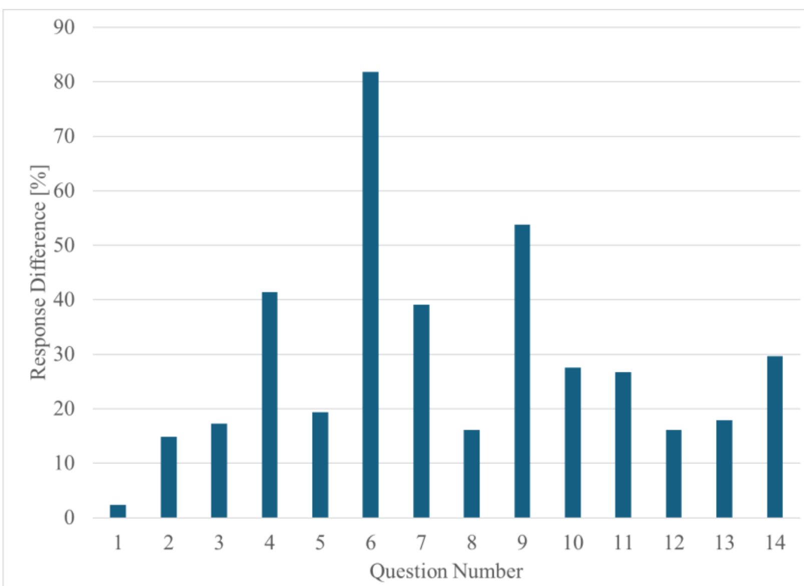

Figure 8: Change in participant answers to questions described in Table IV for post- and pre-participation. Results for questions 4, 6, 7, and 9 were statistically significant.

Conclusions and Future Work

The ocean remote sensing program is shown to be an effective tool for increasing participant confidence in multiple STEM skills areas as well as building awareness of ocean engineering and basic oceanographic monitoring device operations. The program supported eleven participants at the high school and undergraduate collegiate levels with demonstrated improvements in student understanding of the engineering design of ocean hardware and sensor operations. The project resulted in development and deployment of three unique drifter designs and a total of 4 operational drifter buoys. Eight additional drifter buoys are expected to be constructed and deployed into Casco Bay by the end of 2025 to support aquaculture and science initiatives in the estuary.

The students were successful in developing practical drifter buoy designs meeting stakeholder requirements of acquiring time, location, current heading, current speed, surface and subsurface ocean temperatures, turbidity, and dissolved oxygen within performance benchmarks at sampling rates out to 0.2 Hz. The project goal of producing low-cost drifters under $300 was not fully realized. It was determined that durable, low-cost drifters can be constructed at hardware costs between $500-$650 dollars. The drifter data was archived and made available to stakeholders in an open-access, web-searchable format to help empower local aquaculture and climate scientists in the region.

Additional work on this project through 2026 will focus on recruitment of additional students with the goal of recruiting up to 25 total students to complete the build and operations of a next work of 12 drifter buoys and development of the web-based data archive and visualization platform. A final stage of the program is expected in 2027 to enable autonomous search, recovery and redeployment of the drifter devices to reduce the human labor required for manual capture and redeployments under the current operational model.

Acknowledgements

The authors thank Lareen Smith and Brian Tarbox at the Southern Maine Community College for providing technical content in the drifter design and operations. Dr. So Young Han and Drew Sfirri of the University of Southern Maine’s Maker Innovation Studio (MIST) for materials and fabrication support. This project was funded by the Maine Economic Improvement Fund.

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APPENDIX

Table A1: Drifter buoy design specifications incorporating stakeholder feedback

Category	Number	Type *need/want*	Weight *0-5*	Specification	Requirement (Range or Resolution)
Performance	1.1	Need	5	Location	+/- 3 m
	1.2	Need	4	Data Rate	0.2 Hz
	1.3	Need	4	Temperature Sensor	+/- 0.25°C
	1.4	Want	3	Salinity Sensor	+/- 1 ppt
	1.5	Want	3	Turbidity Sensor	+/- 300 NTU
	1.6	Need	5	Current Heading	+/- 2 deg
	1.7	Need	5	Current Speed	+/- 0.01 m/s
	1.8	Want	4	Dissolved Oxygen	+/- 0.5 mg/L
	1.9	Want	2	Nutrient Loading	+/- 0.1 ppm
	1.10	Want	2	Water Color Sensor	450 - 750 nm
	1.11	Need	5	Weight	Buoyant
Environment	2.1	Need	5	Operating Temperature	-20°C to 20°C
	2.2	Need	4	Operating Sea State	1-5
	2.3	Need	5	Ocean Surface	Buoyant
	2.4	Need	5	Salt Water	Non-corrosive
	2.5	Need	3	Ocean vegetation	Smooth exterior
	2.6	Want	3	Coastlines	Impact resistant
Life in Service	3.1	Need	2	Overall Lifetime	5 years
	3.2	Need	3	Mainenance Interval	>1 month
	3.3	Need	5	Maintenance Time	<30 minutes
	3.4	Need	4	Continuous Operation	>24 hrs
	3.5	Want	3	Shelf life/not in service	>6 months
Target Costs	4.1	Need	5	Unit Cost	<$300
	4.2	Need	3	Routine Maintenance	<$50 per service
Product Safety	5.1	Need	5	Boater Visability	Bright colors
	5.2	Need	3	Ecological	Non-toxic
	5.3	Need	5	Accident	Contact Info Provided
	5.4	Want	3	Deployment	Single operator

Table A2: Itemized component list and cost breakdown for drifter buoy V2

Category	Vendor	Part #	Description	Cost	Number	Amount
Housing	McMaster-Carr	4880K249	4-way tee, 3" schedule 40 pipe adapter	$ 29.36	1	$ 29.36
Housing	McMaster-Carr	4880K48	3-way tee, 3" schedule 40 pipe adapter	$ 25.25	1	$ 25.25
Housing	McMaster-Carr	4880K78	4" schedule 40 straight Female socket	$ 8.72	1	$ 8.72
Housing	McMaster-Carr	4880K851	4" schedule 40 hex pipe male socket plug	$ 14.43	5	$ 72.15
Housing	McMaster-Carr	48925K308	4" schedule 40 PVC water pipe, 2ft	$ 31.10	1	$ 31.10
Housing	McMaster-Carr	69945K118	3-1/4" Polycarbonate washdown enclosure	$ 39.37	1	$ 39.37
Sensors	McMaster-Carr	3871K55	Thermocouple probe, type K, 6" x 1/4"	$ 53.70	1	$ 53.70
Sensors	Digikey	1597-109020022-ND	Air530 GPS RF Grove Platform Board	$ 13.10	1	$ 13.10
Sensors	Adafruit	4101	MCP9600 I2C Thermocouple Amplifier	$ 15.95	1	$ 15.95
Sensors	DF Robot	SEN0237-A	Gravity Analog dissolved oxygen kit	$ 169.00	1	$ 169.00
Sensors	DF Robot	SEN0189	Gravity Analog Turbidity Sensor	$ 9.90	1	$ 9.90
Sensors	Amazon	B06XVZ6Y4T	LandSeaAir #54 GPS Tracker	$ 9.95	1	$ 9.95
Electronics	Digikey	282-AF16GUD3-WAAXX-NI	16 GB microSD memory card	$ 22.00	1	$ 22.00
Electronics	Amazon	B07MTTLF75	Micro SD Card Reader Module Memory Storage	$ 1.78	1	$ 1.78
Electronics	Amazon	B07ZV8FWM4	ElectroCookie Solderable Breadboard	$ 1.60	1	$ 1.60
Electronics	Amazon	B0046AMGW0	Arduino Mega 2560 REV3	$ 48.90	1	$ 48.90
Electronics	Amazon	B07T6XWZKN	DaierTek Waterproof Toggle Switch	$ 4.00	1	$ 4.00
Electronics	Amazon	B08FTK2W7Z	2x USB 9V Lithium-Ion Rechargeable Batteries	$ 11.95	2	$ 23.90
Electronics	Amazon	B09C5K91H7	0.96 Inch OLED Display 128x64 Pixel	$ 3.00	1	$ 3.00
Electronics	Amazon	B08SL9X2YC	9V Battery barrel jack connector	$ 0.49	4	$ 1.96
Hardware	McMaster	5084N112	Al Submersible Cord Grip for 0.250"- 0.310"	$ 5.27	2	$ 10.54
Hardware	McMaster	5084N128	Al Submersible Cord Grip for 0.69"- 0.81"	$ 7.57	1	$ 7.57
Hardware	Hamilton Marine	756424	FLAG MARKER 7" X 9" YELLOW NYLON	$ 1.85	1	$ 1.85
Hardware	McMaster	7243K128	Fully Insulated Quick-Disconnect Terminals	$ 7.33	1	$ 7.33
Hardware	McMaster	7243K131	Fully Insulated Quick-Disconnect Terminals	$ 7.33	1	$ 7.33
Hardware	McMaster	8543K73	Structural Fiberglass Rod, 1/4" Dia, 2 ft.	$ 3.01	1	$ 3.01
Hardware	McMaster	5415K87	301 SS Band Clamp, 3-5/8" to 6-1/2"	$ 3.06	2	$ 6.12
Hardware	MatterHackers	MY6CYEZM	1.75mm PLA 3D Printer Filament, 1 kg	$ 20.87	0.25	$ 5.22
Hardware	McMaster	74605A91	PVC clear cement	$ 8.73	1	$ 8.73
				Total Cost:		***$ 642.37***