CAUTION – An Innovative Aquatic Platform to gather Water Quality Data for Environmental Studies

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Abstract

CAUTION – Catamaran-type Autonomous Underwater-sensing Twin-propped Instrumented Ocean Navigator platform was initiated during the summer exchange program of 2013 supported by Maryland Space Grant Consortium (MDSGC) as an integral component of the AIRSPACES – Air-propelled Instrumented Robotic Sensory Platform for Assateague Coastline Environmental Studies project at University of Maryland Eastern Shore (UMES). Nutrient run-off from agriculture, poultry farms, and other anthropogenic influences are threatening the health of the Assateague and other coastal bays of the Delmarva Peninsula. While manned boats can be navigated in certain areas of the bay, many locations important for environmental and other scientific studies are too shallow or spatially constrained to be accessed by large boats or accessed by foot from the shore. The AIRSPACES project is directed by faculty in engineering and environmental sciences at UMES and involves a multidisciplinary team of students to design and utilize innovative remote controlled and/or autonomous air-propelled, small-scale (less than 1.5m in length) aquatic platforms instrumented with various sensors including GPS, depth, pH, dissolved oxygen, salinity, and nitrate to measure the geo-located water quality parameters in the Assateague Bay and other water bodies. Sensory platforms such as CAUTION that are being developed by the project team not only provide an innovative and challenging learning framework for the students but also contribute to a critical need in the region. An exchange student from the University of Maryland College Park (UMCP) who was supported by an MDSGC scholarship, has so far led the CAUTION efforts with support from UMES students. In this paper, we report novel features of the platform and preliminary trials with data collection runs in remote-controlled and autonomous mode. All spatial and water quality related sensory data are recorded to a memory card on the boat for subsequent data analysis and mapping efforts.

1. Introduction

Nonpoint source pollution is caused by the transport of natural and man-made pollutants via rainfall or snowmelt into lakes, rivers, and coastal waters. Some of the largest sources of these pollutants include fertilizer from agriculture, animal wastes from poultry farms, and other anthropogenic sources. The aggregation of these nutrient and sediment loads from run-off can result in a state of eutrophication in the impacted water body. These increased levels of nutrients can lead to the acidification of the water and the development of opportunistic micro and macro algae. An algae bloom can prevent sunlight from penetrating the surface of the water leading to a reduction of photosynthesis beneath the surface. A state of anoxia will occur when the water is completely depleted of oxygen leading to the death of native organisms in the water body. The collection of biomass resulting from decaying organisms and algae further increases the toxicity of the water ultimately making it uninhabitable and a serious health risk to humans and other organisms that rely on the water body. Figure 1 provides a schematic overview of the ecological problem associated with eutrophication [1&2].

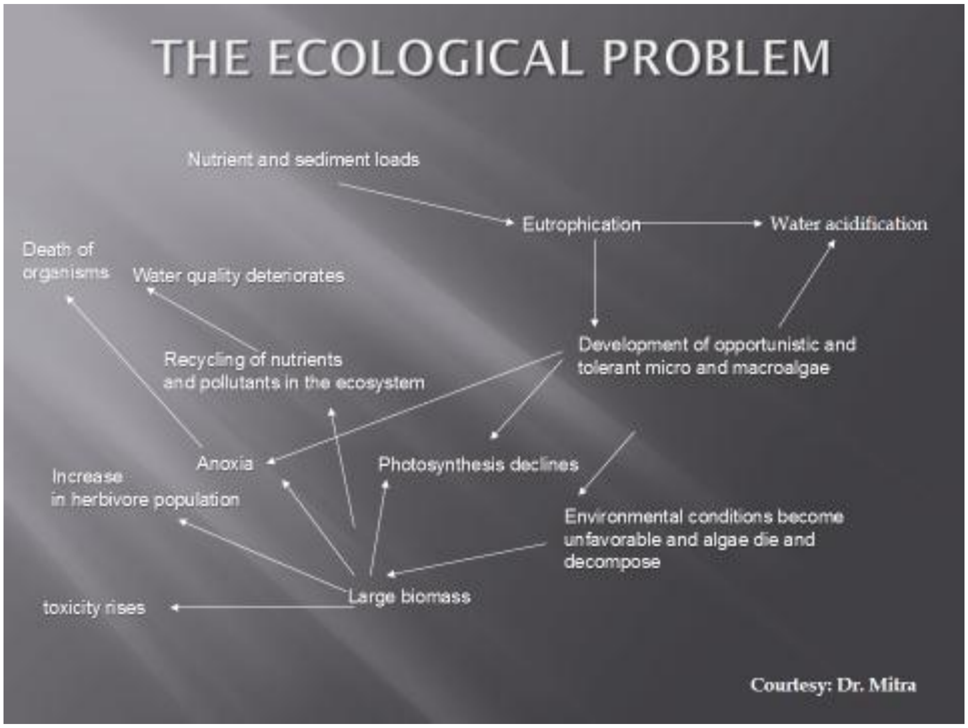


Figure 1: The Ecological Problem

To identify and prevent this scenario from occurring in local water bodies of the Delmarva Peninsula, monitoring techniques need to be implemented that measure water quality indicators such as nitrate levels to assess the state of eutrophication, pH to measure the acidification of the water, dissolved oxygen to determine areas of hypoxia or anoxia in the water, and salinity to identify locations of transition between fresh and brackish water. Current methods for obtaining these measurements usually involve manual measurements taken aboard manned vessels. This can be prohibitive in terms of cost and logistical requirements. Additionally, manned vessels may not be able to access shallow or remote water bodies. A small-scale autonomous robotic platform fitted with sensors capable of collecting the aforementioned water quality data could be effective in monitoring the health of water bodies of interest. CAUTION (Catamaran-type Autonomous Underwater-sensing Twin-propped Instrumented Ocean Navigator) was developed with this goal in mind.

CAUTION, displayed in Figure 2, is a 1.2 m x 0.7 m x 0.3 m autonomous robotic platform outfitted with surface and subsurface sensors for collection of water quality data. It is integral to the Maryland Space Grant Consortium (MDSCG) funded project AIRSPACES[3] (Air-propelled Instrumented Robotic Sensory Platform for Assateague Coastline Environmental Studies) started at the University of Maryland Eastern Shore in the summer of 2009 to study the effects of algal blooms in bays and open oceans. Multiple platforms have been developed and tested under this project. What distinguishes CAUTION from previous platforms is the use of Arduino-based microcontrollers for both autonomous navigation and sensory data collection and a winch system capable of taking sensory measurements at different depths.

Figure 2: CAUTION platform

2. Mechanical Structure

CAUTION was designed to be inexpensive and constructed mainly from locally sourced materials. The twin hulls measure approximately 120 cm long by 10 cm wide and 8 cm high providing a total of 133 N of buoyancy. They are constructed from insulating foam and covered with fiberglass cloth for strength. The electronic housing is a rectangular plastic storage bin with removable cover. The arms attaching the electronic housing to the hull are made from CPVC piping. Aluminum flats (32 mm thick) are used to provide a rigid “skeleton” structure for mounting of the battery, propulsion motors, electronic housing, and winch system. Two additional aluminum flats are used to connect the hulls and help alleviate stress on the arm joints during operation. These mechanical components were acquired from local hardware and retail stores inexpensively (below 60 dollars).

3. Propulsion and Navigation System

CAUTION is driven by two 25.4 cm counter-rotating propellers each individually powered by a 28mm 920 kV brushless motor. Using 30A electronic speed controllers (ESC) with a 12V 9Ah sealed lead acid (SLA) battery; they generate a max thrust of approximately 21.6 N which can propel the boat up to a max speed of 3 m/s given favorable weather conditions. However for standard operation, the boat is limited to 1 m/s to conserve power use and provide operation endurance of up to 1.5 hours.

Air propulsion was chosen based on the intended environments CAUTION was designed for and experiences from previous platforms under the AIRSPACES project. For example, a prior platform attempted to use dual motors with in-water propellers for propulsion. However, the weeds, algae, and other types of vegetation commonly found in freshwater lakes and ponds would often become wrapped around the propeller shaft and in the propellers themselves. This would result in the motors utilizing extra battery power to retain the same speed, and if enough debris became entangled, it would stall the motors. Additionally, there is often no cleared, level area to deploy the platform and the water depth near the shore of a water body may vary depending on weather conditions. Air propulsion circumvented the aforementioned entanglement issues and also allowed better deployment because there was no concern of in-water propellers getting caught on the surface of the ground – in or out of the water.

The Ardupilot Mega (APM) autopilot[4] is the primary component in CAUTION's navigation system. An APM is an open-source autopilot system capable of autonomously controlling unmanned vehicles such as aircraft, cars, and boats. It utilizes a magnetometer and GPS receiver to determine the correct vehicle heading and direct it to pre-designated GPS coordinates (i.e., waypoints). Specifically, it calculates the appropriate left and right pulse-width-modulation (PWM) values sent to the ESC that will result in a heading correction. PWM values recognized by the speed controller generally fall between 1000 ms and 2000 ms. A PWM signal above the neutral or "stop" value of 1500 ms will generate a proportional forward thrust; below 1500 ms generates a proportional reverse thrust.

For example, to turn the boat to the right, a PWM value above 1500 ms will be sent to the left motor and a PWM value below 1500 ms will be sent to the right motor. This effectively results in forward thrust on the left side and reverse thrust on the right side generating a clockwise torque that turns the boat to the right. As the vehicle's motion in the water is constantly affected by waves and wind, these heading corrections are made continuously by the APM throughout the vehicle's trajectory. A proportional-integral-derivative (PID) controller integrated in the APM helps reduce oscillations from the periodic nature of these heading corrections. Figure 3 displays the planned trajectory (yellow line) versus the actual trajectory made by the vehicle (light blue line) in a sample mission. The effect of wind and waves on the trajectory can clearly be seen from the perturbations in the actual trajectory. However, the APM successfully guides the platform (displayed in purple) to the designated waypoints (dashed circles with green pins) numbered in the image. The APM also allows customization of various navigational parameters such as: 1) maximum and cruise speed settings which can be adjusted for given wind conditions or to conserve power consumption and 2) waypoint radius which can be adjusted based on how close the vehicle needs to get to a given waypoint before moving on to the next one.

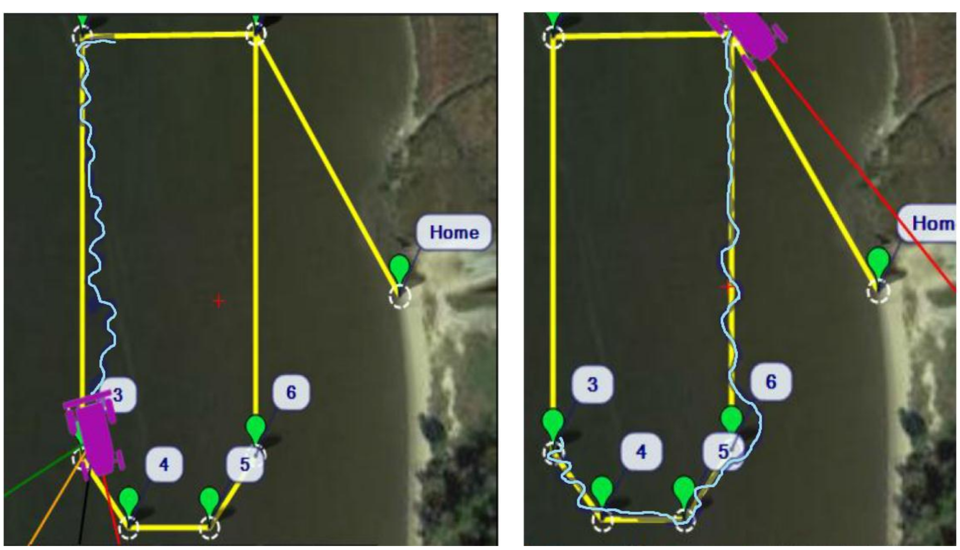


Figure 3: Sample Trajectory from Autonomous Mission

One issue encountered while utilizing the APM is that there was no available function to temporarily stop the vehicle once a waypoint was reached. The water quality sensors utilized on the platform need to sit in relatively undisturbed water for several seconds to accurately record data. The use of electrical relays to effectively shut-off power to the motors at each waypoint was considered. However, this added complexity to the propulsion circuitry. An alternate solution that was decided upon was to have an additional microcontroller board (Arduino MEGA[5]) that could be used to interface with a variety of sensors and actuators, and act as a virtual relay.

The navigational PWM signals from the APM would be read in by the MEGA and passed through to the ESCs during standard navigation. Once a waypoint was reached, a trigger signal would be sent from the APM to the MEGA which would then prompt the MEGA to explicitly send a "stop" PWM value of 1500 ms to the ESCs, effectively stopping the boat for a specified amount of time. Once sensor readings were recorded and the programmed time delay had passed (e.g., 10 seconds or more), the APM PWM values were once again routed by the MEGA to the ESCs and the vehicle moved on to the subsequent waypoint.

4. Sensory System

The Arduino Mega microcontroller is the primary component in CAUTION's sensory and data collection system. The water quality sensors on the platform include two surface sensors from Vernier Software & Technology and two submersible sensors from Atlas Scientific. The Vernier salinity and nitrate sensors generate a raw voltage between 0 and +5 volts when making a measurement that is read directly by the Arduino's analog pins and then converted to appropriate sensor values (e.g., ppm, mg/L etc.) based on sensor specific conversion equations published by Vernier. The Atlas Scientific pH and dissolved oxygen sensors come with an accompanying "STAMP" circuit board that does the conversion itself and then provides that data on a serial communication line to the Arduino. In addition to water quality sensors, there is a depth transducer to record water depth and temperature. A GPS receiver provides additional information including date, time, latitude, longitude, and the number of satellites the receiver has a fix on. These values are then written to a micro flash memory card for subsequent analysis. These and CAUTION's other electronic components are shown in the block diagram in Figure 4.

5. Winch Depth Profiler

CAUTION utilizes a 12V DC brushed motor with a 131:1 gear ratio to deploy the Atlas Scientific submersible sensors. An encoder attached to the motor provides a resolution of 64 counts per revolution of the motor shaft allowing relatively precise control of the motor. An electrical slip ring allows continuous rotation of the winch without any electrical interruption to the Atlas sensor cables. The operation of the winch is as follows: once an autonomous waypoint has been reached or a depth profile is manually triggered, the Arduino obtains the current depth from the depth transducer. The Arduino will calculate the number of encoder counts corresponding to 75% of this depth. The 75% max depth limit can be adjusted based on the known depth of the water but is mainly a safety buffer to prevent the sensors from hitting and getting caught on the bottom. The Arduino then sends the ESC of the winch a signal to lower the sensors until the calculated encoder counts are reached. The Arduino then requests sensor readings from the respective Atlas Scientific

STAMPs while submerged as shown in Figure 5. Once the reading is recorded, the Arduino instructs the winch to return the sensors to their original position.

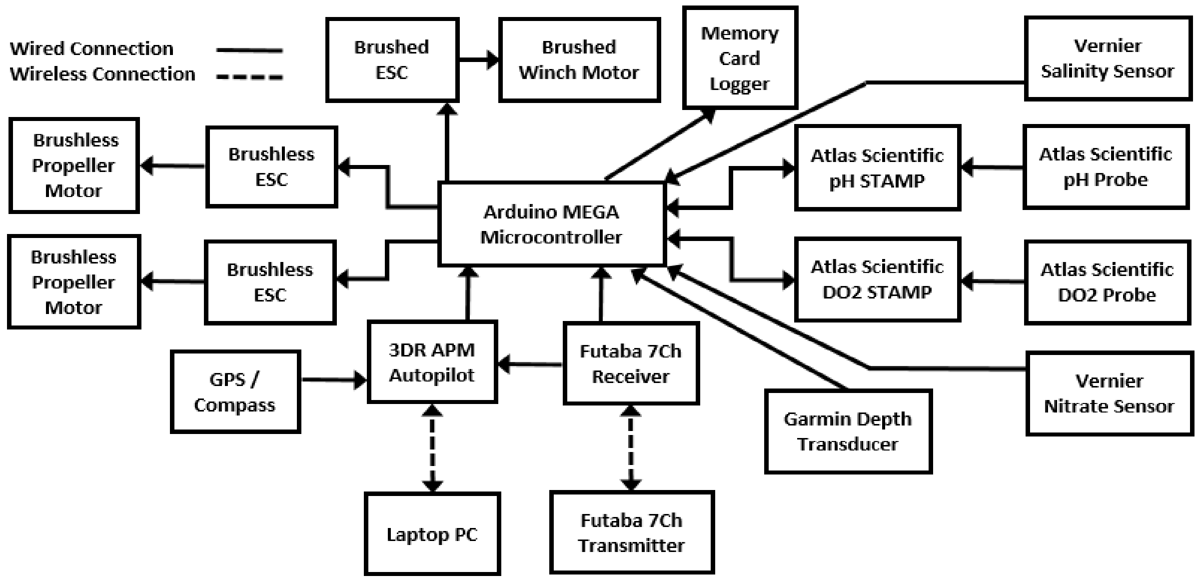


Figure 4: Block diagram of CAUTION's electronic components

Figure 5: CAUTION with submersible sensors deployed

6. Data Collection

Figure 6 below shows a sample collection of data obtained at a UMES pond.

Date	Time	Latitude	Longitude	Speed (knots)	Tracking Angle	Altitude	Satellites	Tot. Depth	Surf. Temp	pH
1/31/2015	21:51:18	38.210216	-75.689674	0.02	180.13	-1.6	8	5.9	35.24	13.72
1/31/2015	21:51:40	38.210151	-75.689392	0.02	180.13	-1	8	6.5	35.24	13.72
1/31/2015	21:52:02	38.21001	-75.689567	0.02	180.13	0.3	8	5.3	35.24	13.72
1/31/2015	21:52:24	38.209884	-75.689796	0.02	180.13	1.1	8	5.1	35.24	13.72
1/31/2015	21:53:23	38.209835	-75.689826	0.02	180.13	1.2	8	3.9	35.24	13.72
1/31/2015	21:56:52	38.210247	-75.689903	0.02	180.13	2.3	8	4.5	34.52	13.72

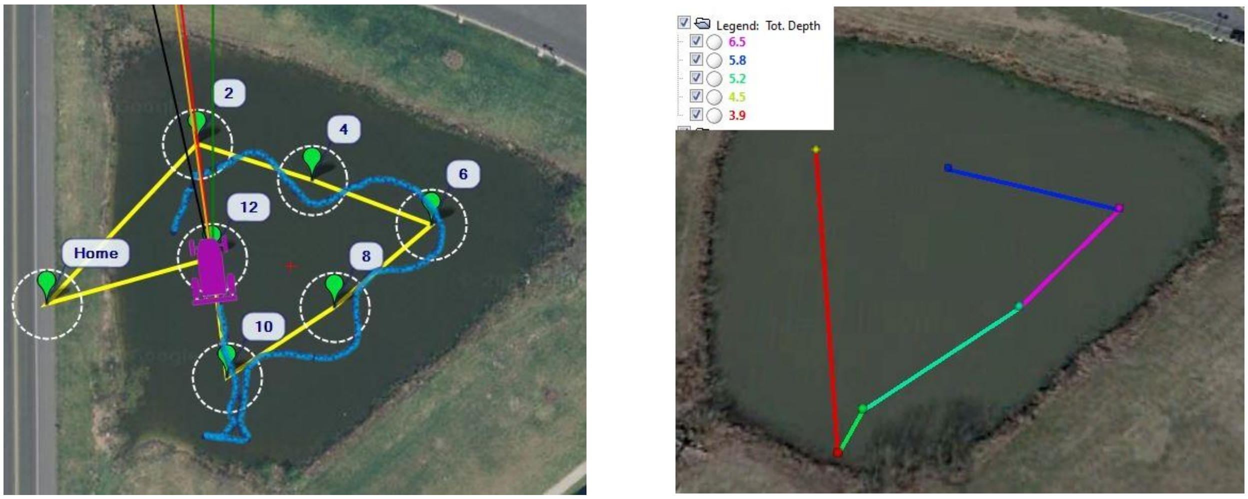
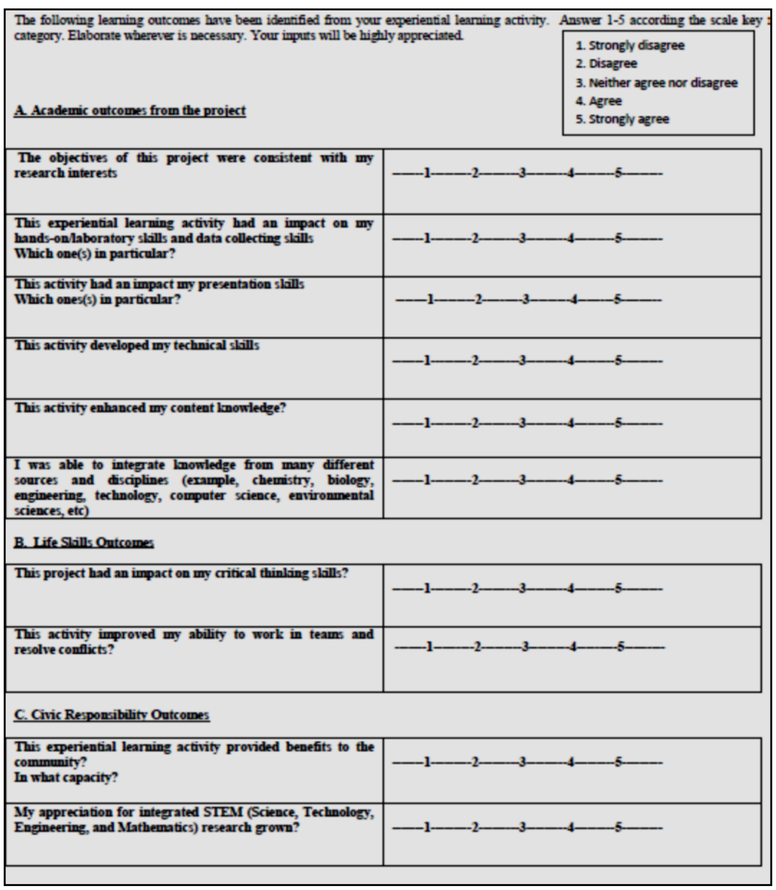


Figure 6: a) (top) Raw csv data recorded onto onboard memory card b) (lower left) Mission waypoints and resultant trajectory c) (lower right) Plotted depth data using GPSvisualizer[6]

The raw data lists measurements obtained from the depth transducer (Total Depth and Surface Temperature), a Vernier sensor (pH), and the GPS receiver (remaining fields). The pH data in this sample was faulty as these values would indicate the pond was extremely basic. The unexpected values may have been a result of using the probe within a few degrees of its minimum temperature rating (0 °C). The undulating motion of the vehicle noted from the light blue trajectory in part b of Figure 6 shows that the PID controller settings require further refinement. Wind speed at the time of testing was forecasted at between 10 and 14 mph which additionally contributed to the oscillations in the motion of the platform between waypoints. Nevertheless, the vehicle tries to reach the circular region of allowable error around the waypoints to collect data close to the coordinates specified in the mission plan. The recorded total depth data was plotted over a Google Earth map of the pond using GPSvisualizer[6] – a free online utility that creates maps and profiles from geographic data. The individual dots represent the data points recorded at each waypoint with the legend indicating the corresponding depth. The lines connecting the data points have been left to more easily distinguish the different data point colors. As this project is a work in progress, items such as the aforementioned pH sensor readings and PID controller settings are currently being investigated.

7. Learning, Development, and Assessment Framework

Consistent with the ABET outcome which requires engineering students to work effectively in multidisciplinary teams, selected undergraduate students are invited to participate in project team meetings related to ongoing cross disciplinary projects led by graduate students and faculty members in engineering, environmental sciences, agriculture, and aviation programs at UMES. Besides AIRSPACES, several other efforts related to agricultural automation, automation for environmental monitoring, and UAV based remote sensing are discussed in these team meetings. The exposure provides a rich learning environment for the students. The UMCP student who is also the lead author of this paper, participated in these team meetings during the summer exchange program in 2013 and 2014. He also attended some of the weekly team meetings in the fall, but given that UMCP is approximately a 3 hour drive from UMES, such visits were infrequent during the regular semester. However, the faculty leaders have encouraged his continued involvement with some of the students who are working in synergistic projects at UMES.



The following learning outcomes have been identified from your experiential learning activity. Answer 1-5 according the scale key category. Elaborate wherever is necessary. Your inputs will be highly appreciated.

1. Strongly disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly agree

A. Academic outcomes from the project

The objectives of this project were consistent with my research interests	——1——2——3——4——5——
This experiential learning activity had an impact on my hands-on/laboratory skills and data collecting skills Which one(s) in particular?	——1——2——3——4——5——
This activity had an impact my presentation skills Which ones(s) in particular?	——1——2——3——4——5——
This activity developed my technical skills	——1——2——3——4——5——
This activity enhanced my content knowledge?	——1——2——3——4——5——
I was able to integrate knowledge from many different sources and disciplines (example, chemistry, biology, engineering, technology, computer science, environmental sciences, etc)	——1——2——3——4——5——

B. Life Skills Outcomes

This project had an impact on my critical thinking skills?	——1——2——3——4——5——
This activity improved my ability to work in teams and resolve conflicts?	——1——2——3——4——5——

C. Civic Responsibility Outcomes

This experiential learning activity provided benefits to the community? In what capacity?	——1——2——3——4——5——
My appreciation for integrated STEM (Science, Technology, Engineering, and Mathematics) research grown?	——1——2——3——4——5——

Figure 7: Student Survey Instrument and Assessment Data

Undergraduate students working in the AIRSPACES project reported here are required to present their progress, share and reflect on their experiences, and get feedback to troubleshoot problems and advance towards their goals through active experimentation during the weekly meetings.

USDA and NASA scientists and engineers who collaborate in these projects are invited to attend these meetings and discuss, advise, as well as work with the students when convenient.

The students participating in these multidisciplinary team projects are surveyed at the end of every semester to assess the impact the exposure is having on some of the desired academic, life-skills, and civic responsibility outcomes using the survey instrument provided in Figure 7. The bar graphs corresponding to the results of the survey conducted at the end of 2014 fall semester are also shown. The survey results indicate that the students perceive the project experience to be valuable. No attempt has been made here to separate the surveys for students participating in different projects as they are discussed in a cross disciplinary team setting on a weekly basis.

8. Summary

The development of CAUTION built upon previous robotic platforms developed at UMES such as SAMPLE[7] (Small Autonomous Monitoring Platform for Lakes and Estuaries) and Rover X-12A (Remotely Operated Vehicles for Environmental Research). The exchange of experiences and ideas with students, faculty, and NASA partners involved with these projects set the foundation for the objectives of CAUTION. Additionally, weekly meetings bringing together students and faculty working on other engineering and environmental science research activities at UMES further diversified the pool of ideas that went into the advancement of the project. CAUTION was developed from the ground up with the goal of being a small-scale autonomous aquatic platform that could be used by students and researchers to obtain water quality data from Assateague and other coastal bays of the Delmarva Peninsula for environmental studies. While it is still a work in progress requiring additional refinements, the project has successfully created a working platform capable of autonomously collecting water quality data.

Acknowledgments

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