Leveraging Competitive Robotics Experience to Spread Marine Education

Ashiria Goel, Colin Szeto, Mabel Szeto, Rishi Veerepalli, and Eesh Vij

***Abstract*—Team Inspiration is a robotics team from San Diego, CA, consisting of passionate middle and high school students. We participate in a variety of robotics competitions including FIRST [1], Robocar [2], and RoboSub [3], an international collegiate level competition. In 2020, our team placed #1 against 33 university and high school teams making history as the youngest team to earn this title. In 2021 our team was accepted to compete in RobotX 2022 [4], an international collegiate competition utilizing an autonomous boat and drone working together.**

In 2011, our coaches created a team and imagined that one day, the elementary school students playing with Lego robots would grow to compete in RoboSub and beyond. Prior to 2019, our team only had experience with ground robots. We took advice and inspiration from experienced teams and connected with marine technology companies to seek mentorship. With the mentorship from professionals, we were encouraged to push ourselves. Through our speaker series, we learned from many professionals from a variety of STEM fields, especially from those in the marine industry. We learned alongside other students about the far-reaching applications of STEM.

In 2019, we began our RoboSub journey starting with the basics: A simple remotely-operated vehicle (ROV) constructed by plastic pipes, brushless motors and on-off control box. We climbed up the complexity scale to prototyping on breadboards and using a reliable off-the-shelf Autonomous Underwater Vehicle (AUV) from Blue Robotics called BlueROV2 [5]. Learning from these platforms, we designed and built our custom AUV, Orange in 2019. The following year we developed Græy which took Orange's design and improved upon it by adding more capabilities and sensors to incorporate intersub communication. In 2021, adapting to the virtual season we created an open source Unity simulation of the RoboSub competition environment to help our team and others to test their systems.

We strive to apply our experience in RoboSub to benefit the local and global STEM education community. Thus, we began collaborating with Porpoise Robotics [6], a team of former submarine engineers, to design low cost underwater ROV to make STEM education more accessible. The ROV is designed to be an affordable robot which can be used to teach STEM, especially robotics and mechatronics, in schools. Sitting well within a consumer price range, the ROV gives schools the opportunity to immerse their students in underwater robotics. In addition to developing the ROV, we have been working with Porpoise Robotics to create a 2-week curriculum for schools to use with the ROV which will aim to teach students Python, underwater dynamics, mechanics, and electrical integration.

By teaching young students about basic principles of marine technology and innovation, we hope to inspire them to explore their interest in the field of ocean engineering. The paper will detail how to inspire more engineers to spread their knowledge and help spark interest in marine education to explore the unknown wonderworld of the ocean.

***Keywords*— systems engineering, marine education, robotics, collaboration, competition, outreach, iterative design process, surface autonomous vehicles, underwater autonomous vehicles, unmanned aerial vehicles, electronics development, marine technology curriculum**

I. Our Learning Process

Our team's motto is: To learn, to share, to innovate, to inspire. Part of the way we fulfill this is by participating in different robotics competitions to expand our knowledge by learning the new technologies associated with each competition. We also encourage team members to apply their knowledge by helping others, whether it be a personal project or a group initiative.

A. RoboSub Competition

In our first year of RoboSub, we started out in late March with only four months to build our robot prior to the competition in the first week of August. We planned out a schedule for our team by working backwards from the competition and submission dates, keeping in mind the capabilities of our team. We began the season with extensive research on previous RoboSub teams to identify which processes and technical aspects would be feasible to apply within our team.

Following the systems engineering processes, mainly the systems engineering V-diagram, we collected requirements for what our AUVs capabilities would need to be at a minimum and established stretched goals.

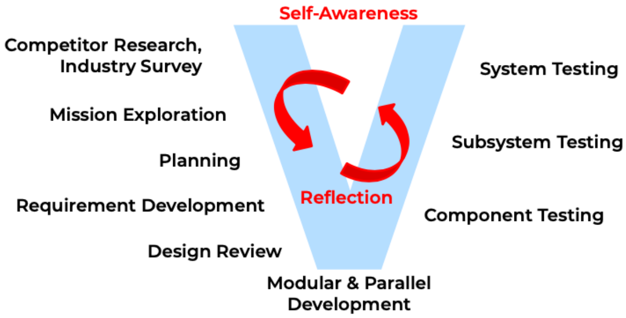

Figure 1. Systems Engineering V Diagram

The schedule was geared towards achieving these goals in a timely manner by checking in on individual team member progress and allowing time to experiment with designs, failures, and redesigns. Throughout this cycle, the team realized the value of the iterative process by taking lessons learned from one design into the next. This process ensured that the team was aligned throughout the season as the requirements were cross-checked with the performance and metrics of the AUV. Some of these metrics included the durability of materials, the reliability of thruster command, ease of testing, software configuration, and the consistency of robot movement. Through subscribing to the systems engineering process the team gained a greater perspective on how each component of the AUV meshed together.

When starting our journey in underwater robotics, we wanted to start with small steps in order to learn the fundamentals. We experimented with basic remote-controlled SeaPerch-like robots made of PVC pipe, to understand how a robot could move underwater.

Figure 2. Team members exploring PVC ROVs.

Once we had experienced using the SeaPerch-like robot, we migrated to an advanced ROV to learn so we could design our own AUV. As a result, we procured BlueROV2, a high performance affordable off-the-shelf vehicle, to learn about the control system, physical structure, and underwater movement. We used its remote control features through the software QGroundControl, but also dove deeper into the connection and data passing between the flight controller, processor and sensors to learn how to create an autonomous system. The flight controller of this off-the-shelf system provided an easy way to get started writing scripts for autonomous motion using the MAVLink protocol. A great amount of documentation from BlueRobotics aided us in getting started.

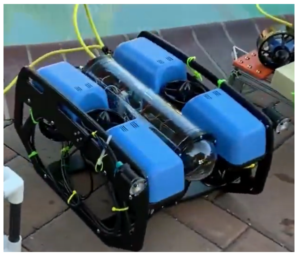

Figure 3. The ROV that we used to learn about AUVs.

We used the components seen in the BlueROV2, to build a test bench emulating a real sub to allow for software tests outside of water. Included was the flight controller, processor, and 8 continuous rotation (CR) servo motor in place of underwater thrusters. This setup saved us significant development and testing time. To test maneuvers the team did not have to ensure that all components were watertight or interact with the wire management system within the hull. All components were connected on the breadboard with jumper wires that could easily be disconnected and reconfigured. This enabled us to verify code and motor configurations quickly.

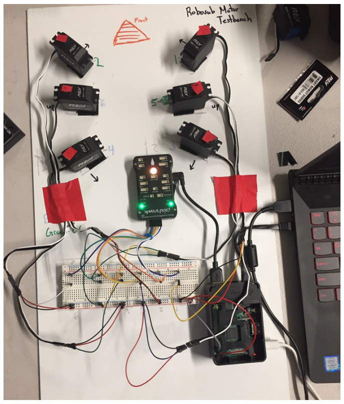

Figure 4. Our test bench, including the key components of an AUV.

Based on the learnings from the BlueROV2 and our test bench, we designed a custom AUV. This AUV, Orange, had electronics and software architecture components very similar to the BlueROV2 example.

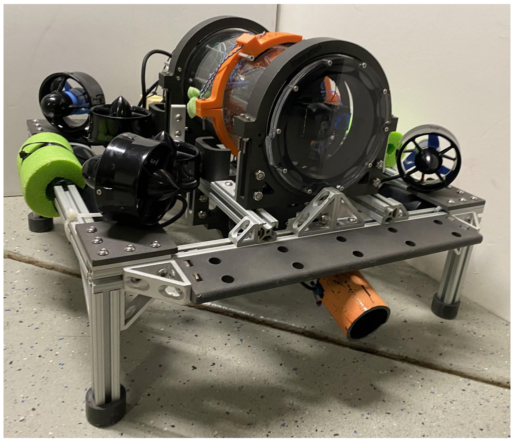

Figure 5. Our first custom AUV, Orange.

As we grew in our first year, we wanted to expand our capabilities with more sensors for our second competition season. We expanded on the tried-and-tested design of Orange to utilize a larger enclosure, allowed for by the modular 80/20 based design of the frame. We could easily adjust the configuration of the frame to replace enclosure clamps and slide on mounts for new sensors where they would fit best.

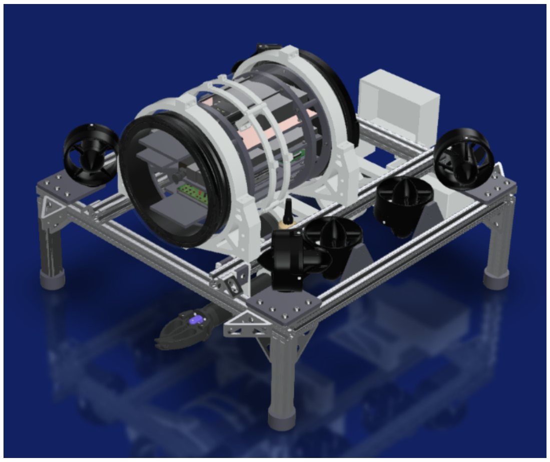

Figure 6. Our second year AUV, Græy.

With more sponsorships of larger materials, such as a 3D imaging sonar, we saw the need to design for a larger enclosure. We increased the length of our electronics enclosure and planned for a PCB (Printed Circuit Board) backplane design for an improved wire management system.

In 2021, we realized that a realistic simulator is paramount to our success, as it can provide a proof of concept and a proof of design, while illustrating a real demonstration of a system in a virtual environment. With a focus on realism, we decided to simulate using Unity, a cross-platform game engine. This allowed us to test our code with realistic sensor input from a competition-like environment. Seeing how useful this tool was for our team, we shared the source code and a user guide with the RoboSub community in the hopes that others can collaborate to make the simulation more accurate.

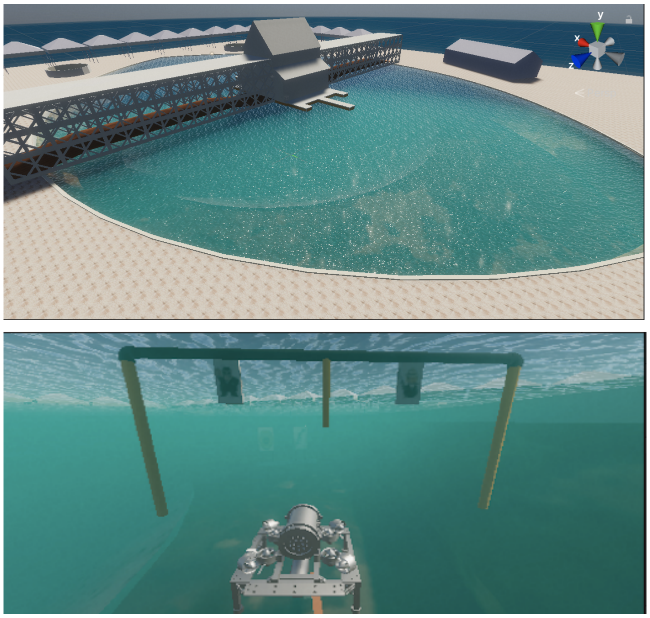

Fig. 7. The current version of our RoboSub simulation.

As we advanced our skills, our mentors have been continuously supporting and guiding us to learn about specific technical concepts and management techniques. We have reached out to product vendors and sponsors with questions about implementing their products and learned from the processes their company uses as well.

B. Surface Vessel (Float Tube)

Through culminating exposure to underwater robotics, we were able to apply our knowledge to motorize a fishing float tube for a fisherman. We designed a simple control system with two thrusters. Based on the feedback from the fisherman, we then revised the materials used to enhance the vessel's performance. We learned the value of high quality materials. We replaced the initial cheap plastic water proof connectors with industry grade dry-mate underwater connectors. This increased the operation time of the system by 400%. This was the team's first project whose performance was heavily impeded by ocean surface waves and heavy wind.

Figure 8. The float tube with thruster attachment mounted

We are now applying what we learned in FIRST, Robocar, drone, RoboSub and the float tube project to our RobotX competition. This competition involved an autonomous surface vehicle and unmanned aerial vehicle to work together and complete missions in a bay. We are working toward developing our awarded 16 foot long Wave Adaptive Modular Vessel (WAM-V) boat to be fully autonomous.

Figure 9. Picture from RobotX website

With RobotX being such a large scale competition, the skills we use will be more than just working with advanced technology in sensors and materials. Our team will need to coordinate logistics for local and international transportation of the WAM-V, ensure safety during development and operation, do major fundraising, and engage with sponsors.

C. Various Marine Robotics Competitions

Our learning and processes used are very similar to what other students do in other marine technology competitions such as the MATE ROV Competition [7], SeaPerch [8], and RoboBoat [9]. In the MATE ROV Competition specifically, teams work towards finding solutions to real world problems such as plastic pollution, climate change, and cleaning waterways. SeaPerch is a grade school level remote robosub program. RoboBoat is an international student competition to design autonomous, robotic boats to navigate through a challenge course. This boat is a smaller scale of the RobotX WAM-V.

II. Applying What We Learned In Marine Technology

Each robotics competition that we have participated in has the goal of preparing students for industry, as well as other practical applications of the skills they have acquired to mimic real-world systems currently deployed around the world for underwater exploration, seafloor mapping, and sonar localization, amongst many others.

A. Utilizing Our Competition Skills

With the technical and communication skills obtained through the various competitions, 10 out of our 15 team members are interning or apprenticing this summer. Colin and Mabel are currently working as interns at Northrop Grumman on the Triton program [10]. They earned the opportunity through competing in RoboSub and presenting about the systems engineering process, which they shared with Northrop Grumman managers and 2020 summer interns. Triton is an Unmanned Aircraft System that is used by the United States and allies. The autonomous drone uses an array of sensors to perform ocean surveillance.

Other students are participating in computer vision research and software development for advanced autonomous manufacturing used in pharmaceutical applications.

B. Repurposing Our Vehicles for Research

Our AUVs are equipped with sonars, doppler velocity log (DVL), acoustic modems, hydrophones, cameras, and grippers. Using these we can use our vehicle for more than just competing in RoboSub. Connecting a tether to our sub, we can remotely operate it to survey underwater and send back live video feed to help scientists and researchers. This can be helpful to collect data on underwater life or damaged infrastructure and move the field of view as necessary.

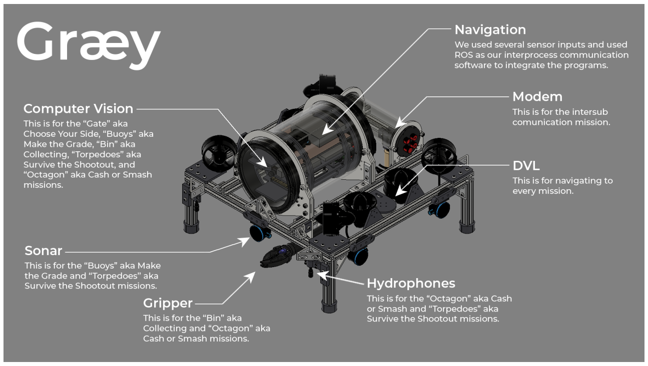

Figure 10. The sensors on Græy highlighted

Sensors such as a 3D imaging sonar can also be helpful to collect similar data in low light environments and scan the sea floor. Hydrophones can be used to listen for specific frequencies from animals or ships underwater allowing scientists to better locate these objects. Additionally, the gripper can be used to collect samples and ocean waste to bring back to shore for scientists to analyze. Along with this remote control capability, our AUV can autonomously navigate the ocean, lake or any other body of water, allowing for minimized operator time. Using the DVL, IMU, and flight controller allows our vehicle to navigate in response to sensor feedback underwater to collect various types of data. This allows individuals from all over the world to activate and monitor the vehicle at their convenience. Using the underwater modems can also allow us to deploy two autonomous vehicles to communicate their status to each other.

III. How We Share with Others

We believe that by teaching, we learn more. Having to explain advanced concepts in simple language to others helps us better articulate and to better understand the concepts we learned. We leveraged our competition success to promote the benefits of STEM education and inspire other students.

A. SWENext

SWENext [11] is the branch of professional engineering society, Society of Women Engineers, that is specifically for K-12 students. SWENext provides access to mentors, competitions, and resources needed to prepare for technical careers. It has an emphasis on outreach and STEM education with a goal of increasing diversity in the STEM pipeline, particularly with getting more females engaged, since diversity and collaboration breeds innovation.

During our research on what might make our RoboSub better, we met with different professors and learned how they use technology to further their marine research as well as what kind of robotics that they want and need to further their research.

Professor Pamela Cosman [12], who teaches electrical and computer engineering at UCSD, talked to our team about her decision to go into academia, experience with being a woman in STEM, and some of her current projects including an underwater vision color correction program. Seeing the wide breadth of her research showed us that our robotics experience can be applied to anything that catches our interest.

Professor Mario Espinoza [13], currently teaching Biology at the University of Costa Rica, partners with biology and engineering students from Cal State University Long Beach, University of Costa Rica, and Harvey Mudd College. When describing his research he explained that both the students and professors on the marine biologist and the underwater robotics sides of the projects are able to gain new insights to their fields due to the different perspectives they provide each other. When talking to our team he explained the need for robotics to support scientists in their research as they need to find the right tools to record the data effectively. In order for him to actively track sharks, he is using an AUV with hydrophones for acoustic and satellite telemetry. For passive tracking, tags are attached to the animals to track a variety of information including: movement patterns, temp, water depth, salinity, pH, oxygen levels, and acceleration. Even with existing technology for collecting data, he pointed out the need to make the devices less obtrusive and more efficient. Tags often fall off in about a year and are able to cause infection. In addition, they often get in the way of the animal's normal movement due to the weight, size, and shape. Furthermore, the amount of data transmitted, battery life, and cost of the sensor all are traded off.

Professor Chris Clark, an engineering professor from Harvey Mudd, highlighted research projects performed as part of the Lab for Autonomous and Intelligent Robotics (LAIR). He explained his goal of integrating robotics and computer science into scientists' research and creating tools for scientists who are not engineers. Some of the projects that he developed are: smart tags, an autonomous tracker, mapping programs that utilize ROVs, and ocean pollution trackers.

Damon McMillan is the founder of Blue Trail Engineering and presented his engineering journey in developing his seafaring autonomous vehicle, SeaCharger [14]. He shared his lessons learned and the broad application of utilizing solar energy to power cheap high endurance projects. In the development process, he realized that most marine technology available commercially was extremely expensive and the criticality of good underwater connectors, so he developed his own company to rectify a portion of the market.

Alan Kenny is the founder of Kenautics and creates robotic solutions for the military, commercial, and academic uses [15]. He shared his progress on the contract jobs from the US Navy. From this, the team realized that engineering can be applied to a wide range of customers and a variety of settings.

We realized that the expertise that the professors and the professionals we interfaced with is invaluable information that should be shared with the community. Meeting with different STEM professionals and learning what kind of projects they do and sharing that enthusiasm with other students to display the breadth that STEM covers and give them something to aspire to emulate.

*B. P*orpoise Robotics

We strive to apply our experience in RoboSub to benefit the local and global STEM education community. Thus, we began collaborating with Porpoise Robotics, a team of former submarine engineers, to design low cost underwater ROV to make STEM education more accessible. The ROV is designed to be an affordable robot which can be used to teach STEM, especially robotics and mechatronics, in schools. Sitting well within a consumer price range, the ROV gives schools the opportunity to immerse their students in underwater robotics.

Figure 11. Prototypes of the Porpoise Robotics ROVs.

In addition to developing the ROV, we have been working with Porpoise Robotics to create a two-week curriculum for schools to use with the ROV which will aim to teach students Python, underwater mechanics, and electrical integration.

The lessons students will learn from this course are designed to provide a basis for a STEM future. Python, a programming language quickly becoming an industry standard, has been crucial in aerospace, financial, medical, and maritime industries. In fact, several large cap companies such as Apple, NASA, and Amazon use Python to handle a majority of their operations -- ranging from small background processing to deep machine learning. By learning the fundamentals of Python through this course, students will be far more prepared to handle opportunities that increasingly require use of programming.

The electronics contained within the ROV are a variety of custom-designed PCBs which students will be able to analyze collectively in a class setting. From the PCBs students will be able to learn about wiring schematics and basic electrical circuits. They will be able to understand the fundamentals of electricity with voltage, amperage, and current, as well as physical parts like resistors and relays. The goal of all this is to provide students with the ability to create their own circuits if they so choose.

The mechanical portion of the course will teach students the basics of design and the decisions which have to be made to create a physically effective system. It will explain why the AUV is designed as is and the benefits it provides for more efficient and adept maneuvering. Concepts such as parallel prototyping and evolution of materials/designs will also be covered.

By using and combining all the lessons learned from the other sections, the course will focus heavily upon the System Engineering method and its aid in creating the AUV presented before the students. Afterall, the system engineering method has shown time and time again it is crucial in both our team's robotics competitions and in the development of this AUV.

Porpoise Robotics' STEM courses are enjoyed by students of Mira Costa College Girls STEM Camp; USC Upward Bound, UC Riverside University STEM Academy; Ocean Discovery Institute Computer Controlled Ground Vehicles; Rancho Minerva Middle School After School Robotics; Coral Reef Research Foundation, Palau; Micronesia Intro to Mechatronics.

C. Media Coverage

We appeared on ABC's The List which highlighted our team's success to a worldwide audience on National Inventors Day. We promoted locally through news appearances on ABC10 and CBS8 stations, along with local newspapers, magazines, and school district letters. We host open houses at the end of each month for other robotics teams and the public to share insights and learn about our projects. This has been slowed due to COVID restrictions but our speaker series and website became our digital sharing platform.

D. Marine Technology Curriculum

Our team also has experience in organizing week-long camps for students to learn the basics of robotics and get involved in STEM. We create lesson plans outlining the lesson flow and takeaways for students. With our newly acquired PVC pipe ROVs, we plan on teaching students interested in robotics the basics of underwater movement and control.

Using these ROVs, students will be able to learn about hydrodynamics. They will explore how individual thrusters can push water and how multiple thrusters working together can push an underwater vehicle in different directions. This will include knowledge about how vectors add and subtract when looking at lateral movements with diagonally angled thrusters.

Once experienced with the PVC structures, students will have the chance to research alternate structures and materials that can be used to construct a similar or more complex vehicle. Examples may include materials used on our AUVs such as 80/20 aluminium extrusions and acrylic tubes. This will involve learning different ways to seal the electronics in a watertight area and the design of the enclosure that holds those materials.

As a result of trying out different materials, students will realize that each material has a different buoyancy and some of these may cause the vehicle to sink. They will be able to explore different weights and buoyancy materials to balance the vehicle and counter the unwanted effects of any materials used.

Once students understand the basics of the physical vehicle, they will move to learning the programming aspects. Using our AUVs which have drone flight controllers, which handle the low level movement commands, the students will learn that we can use this controller because the six degrees of freedom in the air are similar to underwater conditions with a different medium. Students will learn about how the processor, flight controller, sensors, and other components are interconnected. Accessing the Nvidia Jetson Nano processor, chosen for its small size and economical price, students will be able to try basic autonomous commands such as moving forward/backward or up/down. With a little more experience, students can combine these maneuvers to translate these control mechanisms into kinetically moving through a specific path and include rotations such as roll, pitch, and yaw.

Introducing key sensors such as cameras, sonar, and DVL will allow the students to expand the way that they make decisions to move the vehicle autonomously. Using OpenCV, the students will be able to use simple programs to select a certain color from the camera feed. This will allow them to work with RGB (Red Green Blue) values and further their understanding by drawing bounding boxes around the area of color detection or outputting coordinates. The functionality of the sonar sensors will be explained and students will be taught how to read the data through the program. This data can be used to write a basic program to move a specified distance from a wall, teaching students how to make autonomous motions on the AUV based on sensor feedback. They can learn about loops and check the data from the sensor compared to the target value, moving thrusters to align the two. Through these programming tasks, students will realize that it is important to know how far you have moved, bringing them to the DVL. They will be able to get data from the DVL and brainstorm how to use this sensor and create a grid system across the pool.

Students would get to experience the use of our Unity simulator including its sensors and AUV movement functionality. We would invite students and industry professionals to collaborate with us and share their feedback through our website [18] to help make the simulation platform more useful for everyone.

Acknowledgements

Team Inspiration would like to thank the following sponsors: Northrop Grumman, Qualcomm, Biosero, Kenautics, Water Linked

[16], Aquarian [17], Blue Trail Engineering, Medtronics, ePlastics, Nvidia, Sempra Energy, MathWorks, Solidworks, tinyVision.ai, Manna's Martial Arts, Metal Master, Jet Brains, Forecast 3D, and Roboctopi. We are grateful to our mentors: Jack Silberman, Alex Szeto, Amit Goel, Pat McLaughlin, Venkat Rangan, Teresa To, Kris Chopper, Kenzo Tomitaka, Rory Miller, Ralph Morales, Kevin Bowen, Andrew Raharjo, Alan Kenny, John Roscoe-Hudson, Debra Kimberling, and Cris O'Bryon. We appreciate the Robonation organizers for hosting the competition to challenge us and teams around the world. We thank Porpoise Robotics for the partnership and opportunity to design low-cost underwater remotely-operated vehicles and their desktop development systems for STEM education. Lastly, we are indebted to our parents for their continuous support.

References

[1] For Inspiration of Robotics Science and Technology. https://www.firstinspires.org/ (accessed July 18, 2021).
[2] "An opensource DIY self driving platform for small scale cars." Donkey Car. https://www.donkeycar.com/ (accessed July 18, 2021).
[3] "RoboSub 2021." RoboSub. https://robosub.org/programs/2021/ (accessed June. 20, 2021).
[4] "Welcome to RobotX." RobotX. https://robotx.org/ (accessed June. 20, 2021).
[5] "BlueROV2." BlueRobotics. https://bluerobotics.com/store/rov/bluerov2/ (accessed June. 20, 2021).
[6] "Educational STEM Program" Porpoise Robotics. https://www.porpoiserobotics.org/ (accessed June. 20, 2021).
[7] "Take Bluetech to New Depths." MATE ROV Competition. https://materovcompetition.org/ (accessed July 18, 2021).
[8] "Welcome to SeaPerch." SeaPerch. https://seaperch.org/ (accessed July 18, 2021).
[9] "Welcome to RoboBoat." RoboBoat. https://roboboat.org/ (accessed July 18, 2021).
[10] "MQ-4C Triton." Northrop Grumman. https://www.northropgrumman.com/what-we-do/air/triton/ (accessed June. 20, 2021).
[11] "SWENext & SWENext Clubs." SWE. https://swe.org/k-12-outreach/swenext/swenext-clubs/ (accessed July 18, 2021).
[12] "Faculty Profile Pamela C. Cosman" UC San Diego Jacobs School of Engineering. https://jacobsschool.ucsd.edu/faculty/profile?id=28 (accessed July 18, 2021).
[13] "NSF Funds Interdisciplinary Engineering, CS and Biology Research." Harvey Mudd College. https://www.hmc.edu/about-hmc/2020/07/24/nsf-funds-interdisciplinary-engineering-cs-and-biology-research/ (accessed July 18, 2021).
[14] "About Us." Blue Trail Engineering. https://www.bluetrailengineering.com/ (accessed Apr. 23, 2021).
[15] "Meet Alan Kenny of Kenautics in Encinitas." SDVoyager. http://sdvoyager.com/interview/meet-alan-kenny-kenautics-encinitas/ (accessed Apr. 23, 2021).
[16] "Applications." Water Linked. https://waterlinked.com/applications/ (accessed May 7, 2021).
[17] "Aquarian Hydrophones." Aquarian Audio & Scientific. https://www.aquarianaudio.com (accessed Apr. 15, 2021).
[18] "Team Inspiration." Team Inspiration. https://team11128.wixsite.com/main (accessed Jul. 26, 2021).