

Diving Deeper: Advancing Underwater Robotics Education through SeaPerch Adaptations and Marine Industry Partnerships

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Jian Bin Wu is a Systems Engineering researcher at the University of Rhode Island with over three years of experience in delivering end-to-end technical prototypes. His expertise spans the integration of hardware and software, specifically focusing on the intersection of autonomous robotics, computer vision, and advanced data pipelines. As a Graduate Research Assistant with the National Institute for Undersea Vehicle Technology (NIUVT), Bin has spearheaded diverse projects, including the structural and control-layer adaptation of underwater robotic platforms and the development of real-time operator intent classification systems. His Master's thesis research in cognitive state modeling was conducted in partnership with the Naval Undersea Warfare Center (NUWC) to ensure technical depth and mission-relevance. Bin specializes in architecting robust systems in resource-constrained environments, bridging the gap between theoretical research and functional, real-time demonstrations.

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Megan is a graduate of the University of Rhode Island, where she earned both her M.S. and B.S. in Ocean Engineering. Her graduate research focused on evaluating LiDAR sensing systems for near-field wave elevation measurements, including field validation of an Ouster OS1 system. Her broader technical experience includes hydrodynamic analysis, offshore renewable energy systems, and numerical modeling, with a senior capstone centered on the design and optimization of floating offshore wind turbines in the Gulf of Maine.

Megan currently serves as the Undergraduate Research and Outreach Coordinator for the URI Navy STEM Coalition, where she leads the development and implementation of K–12 engineering programming and supports undergraduate research engagement. Her work bridges engineering research and education, with a focus on expanding access to STEM education and fostering inclusive learning environments.

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Abstract

The workforce needs for naval engineering, marine industries, and Science, Technology, Engineering, and Mathematics (STEM) are projected to be increasing over the next decade, particularly with the commitment to build more full size submarines and remotely operated vehicles (ROVs) than ever before. Engaging K-12 students early and often in repeated exposures to STEM disciplines and opportunities is critical for expanding the STEM workforce. SeaPerch is a nationwide K-12 STEM program that introduces students to naval architecture and underwater robotics through the hands-on design and operation of remotely operated vehicles (ROVs). The existing SeaPerch program is designed to make engineering accessible and engaging by combining teamwork, creativity, and real-world problem solving in an underwater environment. Building on this well established foundation, the Navy STEM Coalition enhanced the SeaPerch system for use in URI Navy STEM BOAT camp, a university-based advanced STEM summer camp, by integrating a Raspberry Pi wireless control system and developing an innovative ballast tank mechanism for improved vertical maneuverability. Expanding the options beyond the basic build allows the project to be appropriate for campers who return in a future summer, as well as older campers in the early high school years, who arrive at camp more advanced than the typical middle school target audience. This redesign thus enhances the educational experience of the traditional SeaPerch program while also allowing the Navy STEM coalition to reuse the basic build summer after summer which helps keep costs contained, maintains high student engagement and introduces important engineering concepts that align with Electric Boat, our industry partner . Integrating concepts like programmable logic, real-time wireless operation, and fluid dynamics can expose students to critical engineering skills that support the future workforce needs of the submarine manufacturing industry partners. This project not only enriched students' understanding of complex engineering principles through iterative design and experimentation but also fostered teamwork and problem-solving skills. Future efforts will aim to refine the system for easier classroom and camp implementation and broader outreach.

Introduction

The SeaPerch (fig. 1) remotely operated vehicle (ROV) platform is widely used in K-12 and early undergraduate education as an accessible entry point to marine robotics. Its low cost, simple construction, and hands-on assembly make it an effective teaching tool for introducing foundational engineering concepts. However, the stock SeaPerch design is limited to basic thruster control through a tethered, switch-based interface. The lack of onboard computation, sensing, and programmable decision-making constrains the complexity of missions the vehicle

can perform and reduces its instructional value as students progress beyond introductory activities.

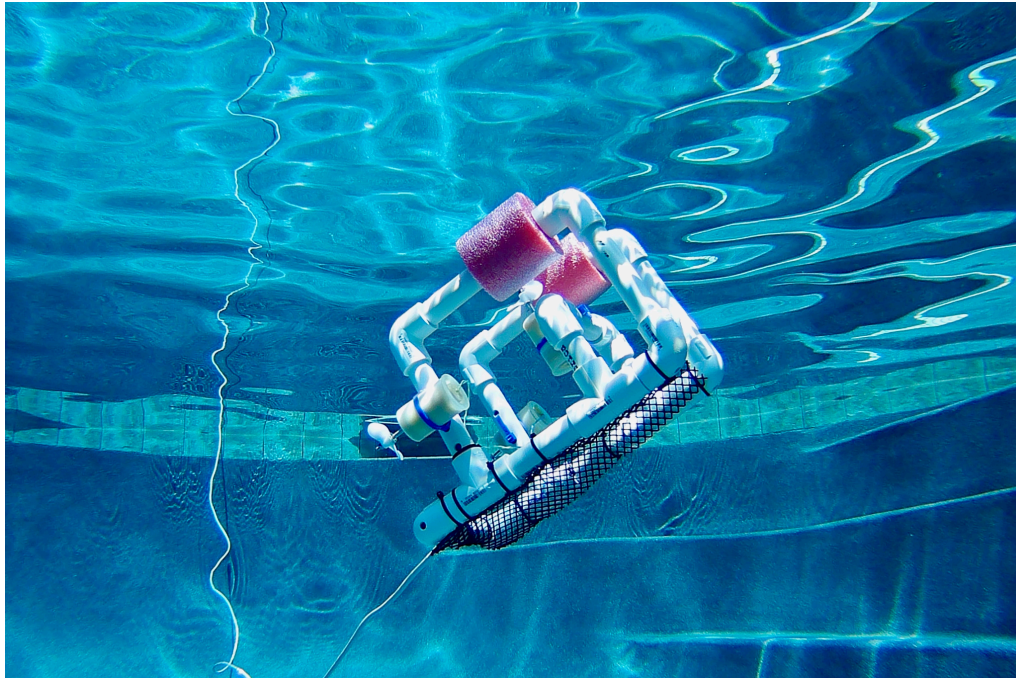


Figure 1: Standard SeaPerch ROV.

To address these limitations, the Navy STEM coalition began a multi-year effort to expand SeaPerch into a platform that can support more advanced robotics learning outcomes while remaining educationally and financially feasible for outreach and classroom use. During the first quarter of 2024, we completed an initial SeaPerch enhancement by integrating a Raspberry Pi as an onboard computer and transitioning vehicle control from fixed electrical switching to software-defined control. Using Python-based scripts and a motor controller interface, the upgraded system enables tunable thruster control and a more intuitive operator interface via a traditional game controller. The addition of an onboard computer also establishes a foundation

for extensible capabilities such as real-time communication, onboard video streaming, sensor-driven behaviors, and programmable maneuvers.

The next improvement addresses the vertical maneuverability and stable depth control of the ROV. In its standard configuration, SeaPerch relies on thruster force to move up or down, which produces slow depth transitions and makes it challenging to hover or maintain a target depth without continuous motor use. To improve vertical control, we have developed a compact ballast system that provides active buoyancy adjustment by taking in or expelling water. Several concepts were evaluated with emphasis on cost, construction difficulty, waterproofing requirements, and suitability for educational implementation. Based on these criteria, we selected a dual-pump ballast configuration as the primary design for this phase because it offers a simple, reliable, and easily teachable approach to buoyancy control.

By expanding both control and vertical maneuverability capabilities, SeaPerch becomes a reusable learning platform that can grow with students' skill levels rather than remaining a single-session activity. The remainder of this paper reviews our prior control-system enhancements, presents the design of an active ballast prototype for improved vertical maneuvering, and outlines future extensions intended to make the SeaPerch easier to build upon in classroom and outreach settings.

Literature Review

SeaPerch Educational Robotics

SeaPerch is an underwater robotics program that allows students to build a low-cost remotely operated vehicle (ROV) using PVC pipe, electric thrusters (DC motors), and a tethered control system (fig 2.). [17]

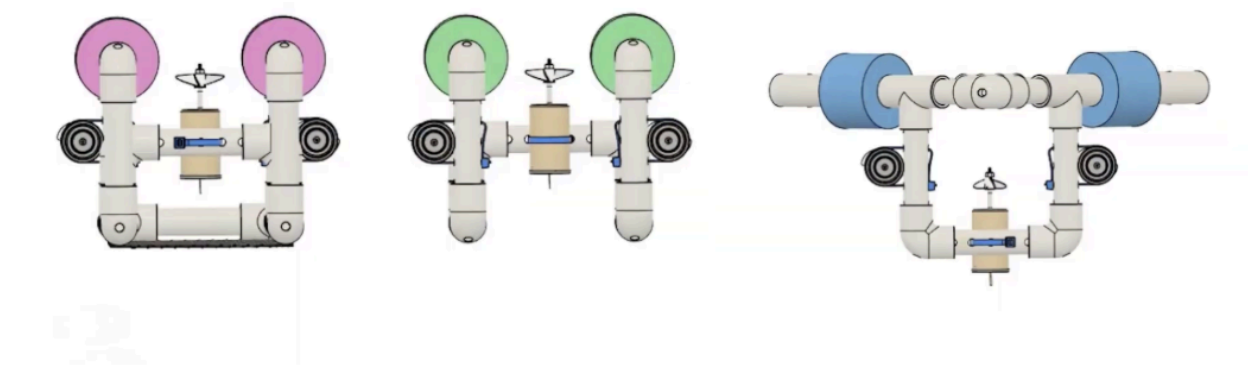


Figure 2: Three iterations of the SeaPerch Standard ROV design

The program is supported by curriculum materials that introduce foundational concepts, including buoyancy, propulsion, basic circuits, soldering, and marine engineering. The SeaPerch platform is designed to lower barriers to robotics participation by providing an accessible kit and structured learning resources that can be used in both in-school and after-school settings (fig 3). Through the build-and-test process, students acquire hands-on experience with engineering design, troubleshooting, and teamwork in a real-world environment rather than solely through simulations. Furthermore, this method provides a preview of what potential career paths may

look like for the students as it directly relates to the work being done by naval architects and those designing and constructing underwater vehicles. For example, the use of PVC pipes for frame assembly resembles shipfitting and pipefitting; while working with the ROV's circuit board and ethernet embedded wires encourages connections to work done by electricians. Through implementation of the SeaPerch build students engage not only in the engineering design process but in various skills used by those working in naval and marine engineering disciplines.



Figure 3: The SeaPerch ROV kit includes PVC frame components, buoyancy materials, a CAT 5 tether cable and butyl rubber tape, and core wiring and safety items. In addition, the kit provides dedicated packs for the controller (PCB, switches, fuse holder and RJ45 jack), thrusters, and propellers.

Within the large landscape of educational robotics, SeaPerch can be situated alongside other platforms that introduce engineering and computing concepts to middle and high school learners

through hands-on building and programming. A comparative discussion across educational robotics systems emphasizes that robotics-based learning is often effective for supporting student engagement and developing an understanding of engineering and computing concepts, especially when learners interact directly with real components and engage in iterative design tasks. This framing aligns closely with SeaPerch, which centers on learning to construct and operate a physical underwater robot. [1].

Recent work also frames SeaPerch as a platform intentionally updated to incorporate emerging technologies while maintaining accessibility. One SeaPerch II effort explicitly targets soft robotics and Arduino microcontrollers, describing tiered modules intended to introduce K-12 learners to sensor integration, feedback control, and soft-robotic actuation [2]. A separate SeaPerch II update presents these additions as part of a broader ecosystem of modules and learning materials that preserves the original platform's accessibility while expanding student capability. Alongside soft-gripper integration, this model emphasizes alternative gripper mounting configurations to accommodate different object shapes and numbers of grippers, and highlights expanded interaction and introductory autonomy-oriented pathways through touch/whisker sensing [3]. Completion of various SeaPerch iterations by students allows for genuine experimentation and increased awareness of how these skills translate to various careers in marine engineering. Use of SeaPerch and SeaPerch II scaffolds student skills providing a set of foundational skills students build on when incorporating advanced electronic capabilities to the ROV.

Beyond platform upgrades, SeaPerch has also been used as the centerpiece of extended, outreach-oriented implementations that resemble camp-style learning structures. In one blended STEM model, undergraduate students build SeaPerch with local middle school groups, develop instruments and instructional materials for the platform, and then return to help students make those instruments and prepare for a culminating "day out" experience and competition. The authors report growth in participation across schools and survey evidence suggests increases in student interest and self-efficacy in STEM areas, highlighting how sustained, hands-on ROV experiences can reinforce engagement over time [4].

As a whole, STEM outreach initiatives provide students with hands-on experiences that allow for connections to careers and “lightbulb moments” which serve as a reminder to all students that they can succeed in STEM related career paths. Redefining students' understanding of what learning might actually look like. A preliminary qualitative study synthesized by researchers using innovative technology to drive interest in STEM careers highlighted positive trajectories for students. The results revealed that 21 out of 27 students felt as if their interest in STEM was sustained or strengthened; while others STEM career interests were piqued after engaging in related programming [16]. Explicit instruction and hands-on learning opportunities in a K-12 instructional setting can provide students of various ages a “low stakes” way to engage with marine engineering and robotics. Creating an environment where students feel supported in sharing their ideas related to advanced technology is key in order for them to become innovative problem solvers equipped with skills needed in today's growing marine and STEM workforce.

These studies position SeaPerch as both a representative educational-robotics platform for teaching core engineering and computing ideas as well as a program that continues to evolve through modular updates and implementation models that support extended, camp-like

engagement for K-12 learners. Updates to the SeaPearch platform makes it more modular and reusable, allowing students to return for repeated exposures and progress from the basic build to more advanced, industry relevant extensions. This progression mirrors authentic engineering iteration and supports sustained engagement in STEM programs that promote pathways into submarine and ROV careers with Electric Boat.

Importance of K–12 STEM Camps

K-12 STEM camps and camp-like outreach programs bridge classroom learning with extended, hands-on exploration by giving students sustained time to build, test, and iterate on real systems. One STEM learning approach uses student ROV projects to integrate engineering design, science concepts, and technology through building and testing activities that culminate in a statewide ROV competition. It uses pre/post measures focused on students' conceptions of STEM principles and interest in STEM topics and careers to argue that this ROV-based experience supports engagement and learning in an informal, project-based structure [4]. Continuing the camp-like model of extended project work, other programs show that camps can broaden access to higher-level STEM experiences by placing students in research-like environments that are difficult to replicate in standard classrooms. A K-12 advanced research camp model illustrates this approach through a week-long program in which high school students work in small teams on engineering and science projects under close faculty mentorship, designed to increase participation and provide hands-on exposure across multiple STEM disciplines [5].

More recent camp formats extend this logic into computing and AI, showing that short, structured experiences can still preserve creativity and project-based learning while introducing modern technical content. An online summer camp pilot introduced machine learning using Scratch-based programming and educational robotics activities, and the study evaluates whether

the experience shifts students' views of Computer Science (CS)/STEM and interest in CS-related pathways [6]. Complementing these robotics- and computing-centered camps, design-oriented, Science, Technology, Engineering, Arts, and Mathematics (STEAM) camps highlight how integrating disciplinary learning with open-ended design can deepen conceptual understanding while strengthening collaborative participation. In one STEAM camp study, upper elementary and middle school students engaged in digital design challenges that integrated coding and global competencies and involved peer sharing and collaboration; the curriculum was developed through iterative design cycles and situated in real-world contexts such as sustainable housing aligned with the UN Sustainable Development Goals, supporting conceptual learning and helping students connect mathematics and science to global issues [7].

Long-running outreach programs further demonstrate how camps can become sustained community-based pathways rather than one-off experiences. The Adventures in Robotics program has operated for over two decades with week-long youth workshops combining programming, teamwork, brainstorming, and age-appropriate mechatronics using LEGO robotics kits. Adventures in Robotics also extends its impact through teacher professional learning, classroom-transfer support, and a mobile roadshow model aimed at underrepresented and economically limited communities [8]. Additionally, an emphasis on arts-integrated computing adds an inclusion-focused lens that helps explain why these informal environments can matter for broadening participation. This suggests that integrating visual and performing arts into K-12 computing can reduce barriers for learners historically underrepresented in CS by valuing creative expression and flexible, student-centered engagement. Across reviewed studies, activities span music, movement, drama, and visual design, and the most consistently reported impacts are positive, including increased interest and engagement, shifts in perceptions of CS

accessibility, and improved confidence outcomes that align well with informal, project-based learning environments [9].

These studies suggest that STEM and STEAM camps are essential because they provide the time, structure, and social setting for students to learn by designing and making, to connect STEM ideas to real-world problems, and to build confidence and interest through supportive, collaborative experiences. By extending learning beyond the constraints of standard class periods and offering flexible entry points including creative and culturally responsive approaches; camps can function as robust pipelines that both deepen STEM understanding and broaden participation in computing and engineering pathways.

The use of SeaPerch as a mode for student engagement in STEM summer camps allows for direct connections to work done in naval and marine engineering environments. In addition, providing the opportunity to engage in these skills in real research environments like universities, further connects students to the research and career opportunities available to them. These opportunities place students and their future career possibilities at the center of the learning experience in order to foster skills needed to meet the demands of the STEM workforce.

Microcontrollers and onboard computing in Education Setting

Microcontrollers and single-board computers such as the Arduino Uno and Raspberry Pi are increasingly used in K-12 robotics because they provide a practical bridge from basic "build-and-drive" activities to higher-level learning in embedded systems and computing.

Compared with purely mechanical builds or switch-box control, these platforms let students connect real sensors and actuators, implement simple decision logic, and observe how code and

circuitry produce measurable behavior in a physical system. They also support structured progression in difficulty: students can begin with straightforward input–output tasks and data logging, then advance toward feedback control, sensor fusion, communication, and autonomy-oriented behaviors as their projects mature. In this way, integrating low-cost embedded hardware elevates robotics from a construction activity into a richer engineering experience. Use of single-board computers on SeaPerch ROVs allows students to interact with electronics, programming, experimentation, and iterative debugging, all skills that align closely with modern robotics practice and prepare students for more advanced STEM pathways. Additionally, students gain first hand experience using this type of technology to improve an already functioning robot.

An instrumentation-focused SeaPerch extension demonstrates how adding low-cost embedded hardware can elevate underwater robotics from piloting to measurement-driven engineering. Introducing an onboard flight recorder built around an Arduino Uno, paired with an Internal Measurement Unit (IMU) and microSD logging, students can capture motion data during robot runs and analyze performance afterward; the same effort also outlines a more extensible onboard electronics architecture intended to support additional sensors and actuators as the platform expands [10].

SeaPerch II projects have used Arduino-based modules to move beyond basic teleoperation, where the ROV's motion is driven by operator commands in real time and scaffold embedded-systems learning through a structured, level-based curriculum that incrementally introduces Arduino programming and sensor integration. [2] A related SeaPerch II update further

operationalizes the microcontroller role and integrates depth-sensing, stabilization, actuators and motor control. [3]

Raspberry Pi-based systems are frequently used in K-12 robotics as low-cost single-board computers that expand what students can do beyond basic device control, supporting operating-system-level computing and a broader range of software workflows while still enabling hands-on electronics and robotics projects. In a comparative discussion of educational robotics platforms for middle and high school, Raspberry Pi is described as a low-cost, credit-card-sized computer used for projects such as robots and web servers, and it is explicitly linked to developing programming skills, with Python noted as the most popular language [1]. In technically oriented high-school STEM instruction, Raspberry Pi is used as the Information and Communication Technology (ICT) platform within project-based experiments, and the reported results emphasize that project-based learning with ICT tools yields student knowledge and skills that are more complex, more systematic, and more permanent than standard instruction [11]. At the robotics-programming interface level, Raspberry Pi can also reduce logistical barriers while keeping programming authentic: a blocks-based environment streams a web interface from a Linux server running on an onboard Raspberry Pi, receives student code wirelessly, and compiles it on the robot, helping learners connect block-based logic to underlying code structures [12].

In applied underwater-robotics projects, the Raspberry Pi is repeatedly used as the preferred onboard computing platform because it supports the same integration tasks found in fundamental research and engineering workflows. In an aquaculture-inspection ROV, the stated aim is to

develop an ROV for aquaculture applications that can provide direct visual information from fishery nets. The Raspberry Pi is described as handling higher-level functions, including video transmission, lighting control computations, and device-to-device communication, illustrating how a Pi can serve as the software-and-telemetry hub in a practical ROV architecture [13]. In a low-cost underwater pipe crack-detection system, the objective is explicitly framed as creating an inexpensive vehicle that can reliably identify cracks using vision. The system uses a Raspberry Pi with a camera and Python-based image processing built on Canny edge detection, a standard computer-vision technique that identifies object boundaries by locating sharp changes in image intensity, which correspond to edges and mark object boundaries. This demonstrates a realistic end-to-end pipeline from data acquisition to automated inspection output [14]. Another low-cost AUV for marine exploration similarly positions Raspberry Pi as the core embedded computing unit, noting use of a Raspberry Pi 4B with Python control software and validation through field testing outside the laboratory, highlighting the importance of reliability, deployment constraints, and iterative testing in marine robotics development [15]. These examples support the broader argument that integrating microcomputers into classroom robotics develops transferable, workforce-relevant skills: students practice coding and debugging, apply iterative engineering design, solve open-ended problems under real hardware constraints, communicate technical decisions and results, as well as collaborate effectively in teams, all abilities that are transferable to real engineering and research work.

System Enhancement of the SeaPerch Platform

Rationale and Design Goals

The initial goal was to improve the control flexibility of the SeaPerch platform beyond the limitations of the standard switch-box controller. While the stock SeaPerch is appropriate for introductory activities, its switch-box interface limits motor control to basic on-off operation. It provides little to no opportunity to teach basic programming or an iterative robotics workflow involving design, testing, and integration. For returning students, the lack of expandability means there is little new to learn after the initial build, thus reducing repeat participants. As repeated exposures are proven to increase positive associations with STEM, it is pertinent for campers to engage in multiple STEM focused experiences. For outreach teams, the basic SeaPerch platform can be a constraint for demonstrating iterative engineering. From a sustainability perspective, limited reusability leads to a “build once, use once” pattern which results in high material waste. To better support material reuse, and deeper learning while decreasing recurring expense, we replaced the standard switch-box control scheme with a programmable control system, enabling adjustable thrust, more responsive piloting, and a foundation for continuous improvement.

Hardware and Software Implementation

To enable programmable control, we integrated a Raspberry Pi as the onboard computing platform. Rather than relying on fixed electrical switching, the Raspberry Pi processes operator inputs and generates motor commands through Python scripts. This created a flexible control framework that improved maneuverability and also established a foundation for additional

capabilities such as sensor feedback, video streaming, and autonomy. In this architecture, the Raspberry Pi functions as the central hub for communication and control.

For thruster actuation, we added an Adafruit motor controller to serve as an interface between the Raspberry Pi and the SeaPerch motors. This allows us to program the motor speed directly in the Python script, setting thrust speed as a percentage rather than just on/off. As a result, the vehicle could be maneuvered more smoothly and precisely, particularly during turns and when navigating confined spaces. The motor controller also provided stable and safe power level delivery during operation.

To improve operator usability, especially in youth camp settings, we replaced the traditional switch box with an Xbox-style controller (Fig. 4); The joysticks and buttons provide a familiar, ergonomic interface that maps naturally to continuous thruster commands. The controller communicates with the Raspberry Pi, with Python scripts converting joystick positions into proportional motor output. This control scheme reduced training time and improved piloting performance as many students were already familiar with the game controller inputs.

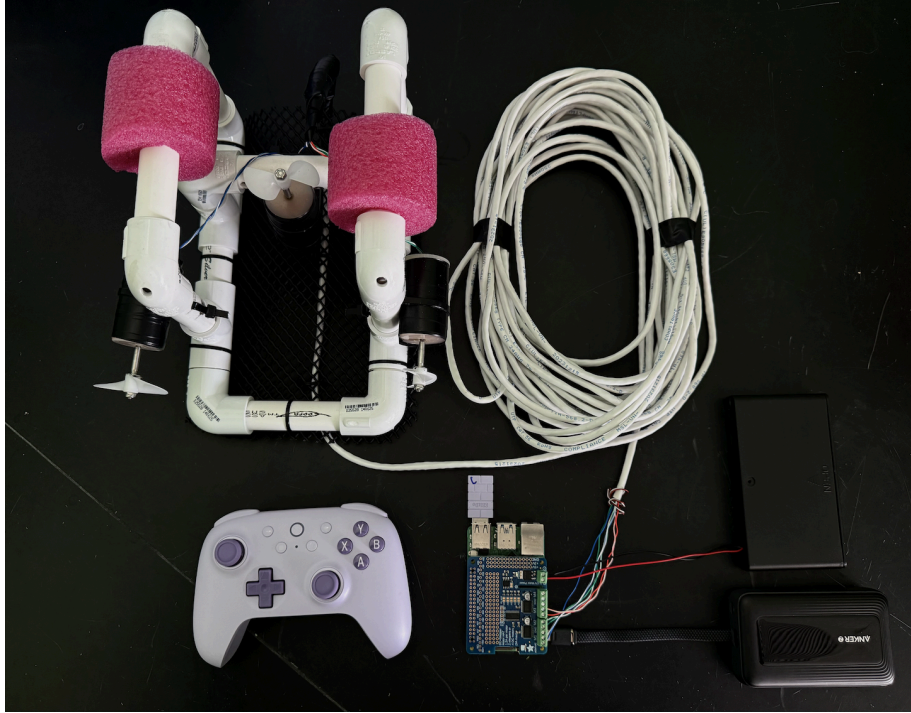


Figure 4: SeaPerch with advanced control operations, including game controller (bottom left) and Raspberry Pi (bottom right).

Camp Deployment and Observed Outcomes

The upgraded control system was piloted during the URI Navy STEM BOAT camp where returning and first-time students used the enhanced SeaPerch platform. Student response was consistently positive, and the Xbox-style controller produced an immediate improvement in perceived usability. Students groups who previously struggled with the switch-box interface found it easier to maneuver the vehicle, and piloting felt smoother, more intuitive, and more engaging.

In addition to improved handling, the Raspberry Pi integration prompted noticeable curiosity and increased technical engagement. Even though programming was not a formal skill most participants had encountered in school, students asked "what if" questions, experimented with

ideas, and expressed excitement when they solved small programming challenges or observed code changes affecting vehicle behavior. Older students, in particular, showed interest in exploring the control logic and understanding how inputs were translated into thruster output. These observations suggest that the enhanced SeaPerch platform can both improve piloting performance and create a natural pathway for introducing programming and engineering concepts at increasing levels of difficulty.

Summary and Implications

Overall, the integration of the Raspberry Pi, Adafruit motor controller, and a Xbox-style controller significantly improved SeaPerch maneuverability and expanded the platform's instructional potential. Students demonstrated higher engagement, better control accuracy, and increased interest in underlying engineering concepts. This initial work also clarified broader limitations of the standard SeaPerch configuration and motivated subsequent efforts to expand functionality further. By extending the system beyond its original design, the platform can support a broader range of robotics learning outcomes and engage more K-12 students through scalable, skill-appropriate activities.

Ballast System Development for Improved Vertical Control

Rationale and Design Goals

Although the upgraded controller and software substantially improved horizontal maneuvering, the SeaPerch still struggled with precise vertical motion. In the stock

configuration, depth changes depend solely on thruster force, resulting in slow transitions and difficulty maintaining a stable depth without continuous motor use. The buoyancy control in the baseline SeaPerch was limited to passive adjustments, including adding or removing pool noodles on the PVC frame and using drilled holes in the PVC chassis to allow water to enter. As a result, buoyancy tuning was difficult and time consuming, since it depended on who assembled the ROV and the specific design choices. To address this limitation, we began developing an active ballast tank system that changes vehicle buoyancy by taking in or expelling water (Figure 5). This approach is intended to enable smoother vertical movement and more stable depth control, while mimicking the actual depth control of full size submarines.

Ballast Pumping Mechanism

The ballast system is driven by two 12 Volt mini submersible pumps rated at 63 gallons per hour. One pump draws water into the ballast reservoir while the second expels water back into the environment. Using a two-pump configuration avoids the need for mechanical valves or more complex plumbing. The pumps are compact enough to fit within the SeaPerch frame and interface with the existing Adafruit motor controller used for the main thrusters (Fig 7). Pump operation is controlled via Python scripts on the Raspberry Pi, allowing flow to be managed directly in software and maneuvered as needed to adjust buoyancy.

Ballast Reservoir Selection

For the ballast chamber, we selected a plant drip irrigation bag from a standard automatic watering kit. The bag acts as a flexible reservoir: it expands as water is pumped in and collapses as water is removed. Its low cost, lightweight construction, and compatibility with small-diameter tubing make it well-suited for a SeaPerch-scale system. The bag provides sufficient volume change to produce noticeable buoyancy shifts while keeping the overall design simple to assemble and maintain.

Tubing and Fluid Routing

Clear vinyl tubing connects the pumps to the irrigation bag and to the vehicle's intake and discharge ports. Tubing length and routing required careful attention because both directly affect flow performance. Longer runs increase resistance and slow water transfer, while overly short runs can interfere with other components or introduce sharp bends. Through iterative testing, a tubing configuration was established that maintains reliable flow while keeping the ballast system compact and unobtrusive (Fig 5, Fig 6).

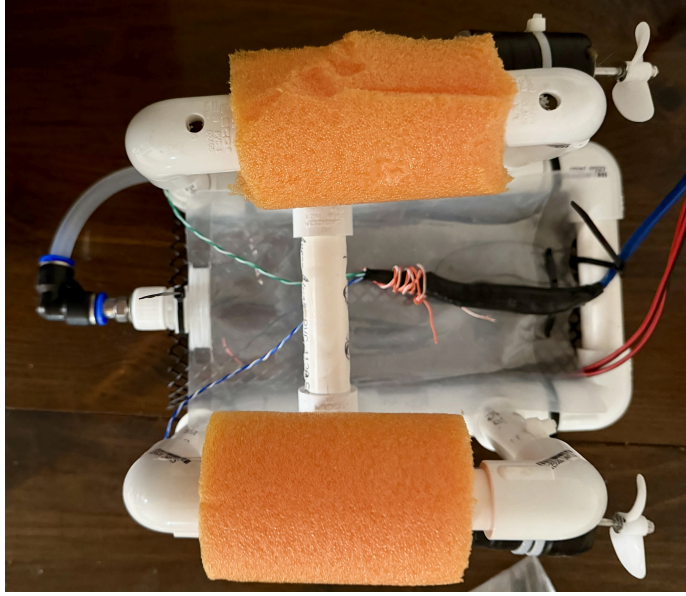


Figure 5: Top view of ROV with Ballast Tank

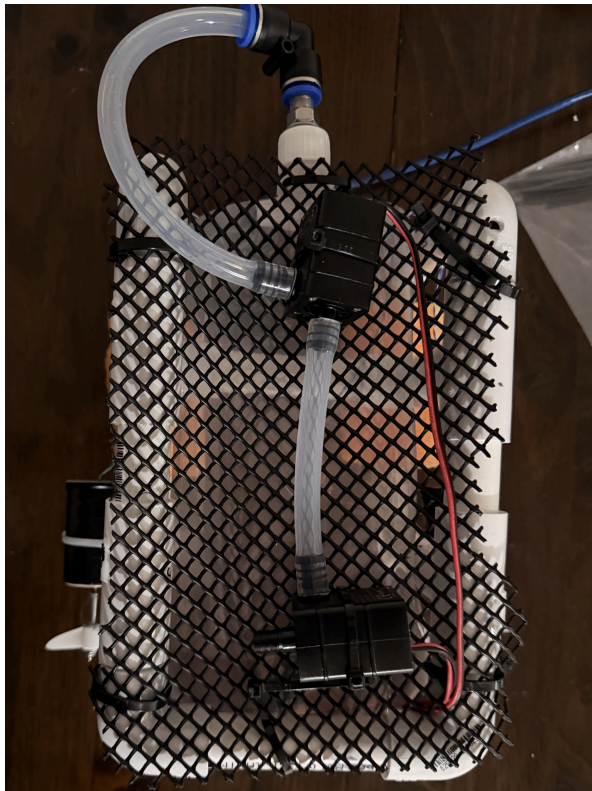


Figure 6: Bottom View of ROV with Ballast Tank

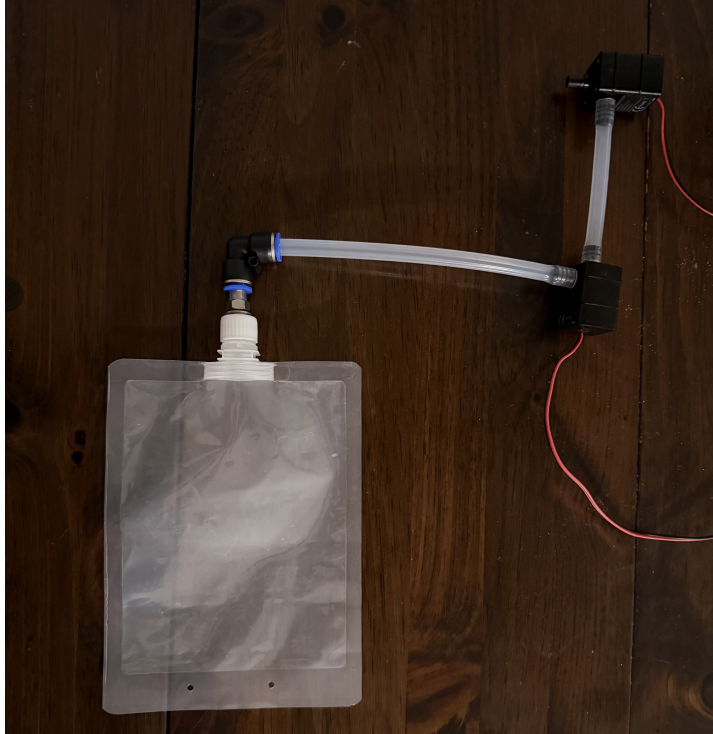


Figure 7: New Additions, "Ballast tank", and 2 water pumps

In order to create SeaPerch advancements that could be replicated in summer camp and formal educational settings whilst remaining cost effective, the Navy STEM coalition designed a three phase improvement system which builds off of the original SeaPerch materials and vehicle components. In summer 2025, the Navy STEM added a Raspberry Pi as an onboard computer, which made the platform significantly more modular. Paired with an Adafruit Motor HAT, the Pi enables software based control and establishes a flexible core that supports future add ons. These components are reusable control modules rather than a one time expense. They can be moved between vehicles and reused across multiple camp sessions, reducing long term costs and making it easier to scale the program. Building on that foundation, our research team's current update is a ballast tank system for active buoyancy and depth control. This add on was enabled specifically because the onboard Pi platform is already in place to handle control logic and motor actuation.

The ballast tank also provides a strong educational benefit by creating a natural environment for design iteration. Students can test, compare performance across builds, troubleshoot, and improve their designs based on observed outcomes. Just as importantly, the ballast tank supports cost efficient expansion. Since the Raspberry Pi and Motor HAT are reusable, introducing a new advanced activity no longer requires buying a new \$199 kit. Instead, the ballast tank adds approximately \$20.33 per build, allowing the program to deliver new, more advanced challenges with a small incremental cost. Additionally, items like SeaPerch tool kits represent one time costs as tools can be reused year to year. Over time, as the control module and other components are reused across sessions, the effective cost per camper decreases, while the learning experience becomes richer and more authentic. This process also allows for students who have participated in standard Seaperch ROV construction to return to participate in advanced level programming and use of original ROV materials allows students to see first hand how vehicle improvements can be made by altering an already functioning vehicle. This process actively encourages critical thinking and activation of prior knowledge to push higher order thinking. Table 1 highlights how SeaPerch builds can be adapted through reuse of materials year to year whilst integrating advanced technology designed to allow students to re-engage in programming and provide opportunities to older students with advanced skills. This implementation emphasizes efforts to make SeaPerch a platform for repeated engagement by students while remaining cost effective and minimizing material waste.

Table 1. Cost Analysis of Implementation Per Vehicle

SeaPerch ROV Kits (Year 1)	SeaPerch With Raspberry Pi (Year 2)	SeaPerch with Ballast Tank (Year 3)

SeaPerch Kit W/Battery \$199	Raspberry Pi 4 \$74.02	Two 12V mini submersible pumps \$14
Traditional Tool Kit \$269	Adafruit Motorhat \$22.50	Plant drip irrigation bag \$2.50
	Wireless Controller \$30	Plastic tubing 2 feet \$1.10
	Portable Battery \$26	Routing (Elbow) \$1.30
	Micro SD Cards \$20	Barb Thru-Bulk Fittings \$1.70
	8 AA Battery Holder \$5	
Total: \$468	Total: \$177.52	Total: \$20.60

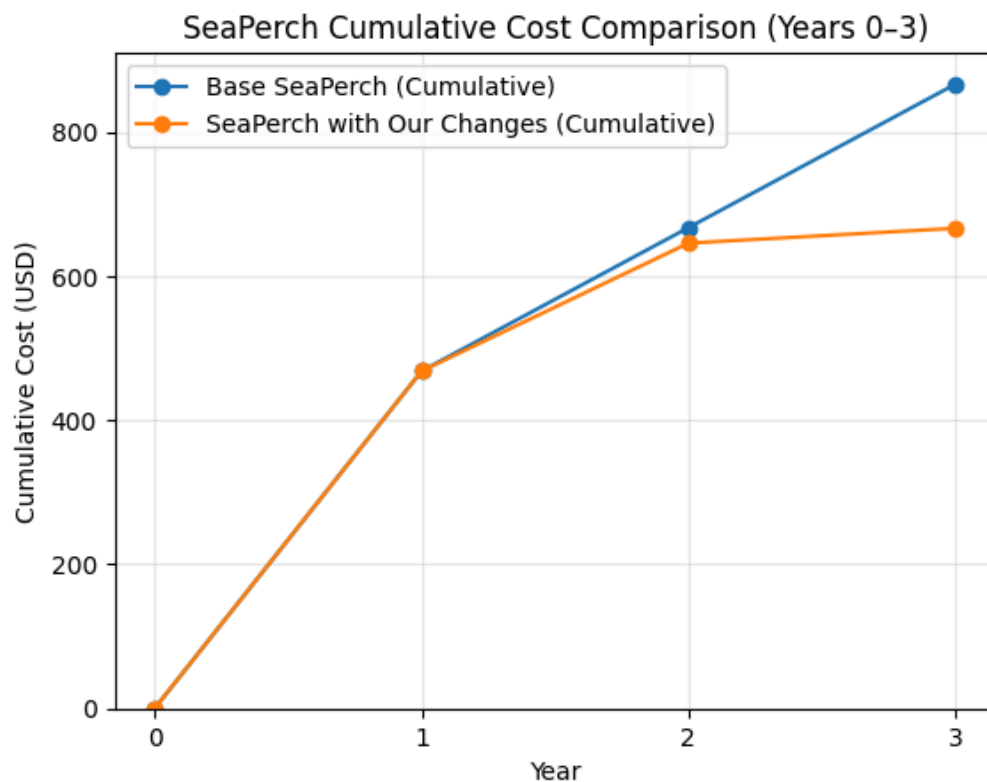


Figure 8: Cumulative Cost Comparison Table

Future Directions for the Upgraded SeaPerch Platform

Mechanical Piston-Based Ballast System

The following significant enhancement planned for the SeaPerch platform is a mechanical piston-based ballast system. Unlike the current pump-and-bag approach, this design uses a high-torque DC motor coupled to a threaded rod and plunger to displace water in and out of a sealed chamber. By advancing or retracting the plunger, the system can precisely adjust internal volume and, therefore, buoyancy, aiming to achieve more predictable, accurate vertical control than fluid-transfer pumps. Although still in early development, this concept also offers students the opportunity to engage with deeper engineering challenges, such as mechanical actuation, waterproof sealing, threaded motion control, and chamber design. Early prototyping suggests that a piston mechanism may offer faster vertical response, improved hovering stability, and more robust depth control in environments that require delicate maneuvering.

Providing two ballast options, a pump based system and a piston base system, gives students more creative control over ROV configuration. Encouraging variation and emphasizing student choice allows for individualization by teams while simultaneously reinforcing engineering decision making through hands-on testing and iteration. Having two different ballast platforms also creates a built-in comparison opportunity. As students test their ROVs side by side, the difference in performance naturally promotes peer discussion about design trade offs and potential improvement. This mirrors a small but genuinely important real world engineering

practice where teams benchmark against a higher performance solution and incorporate what they observe into iterative improvement to their own product

Additional Sensor Integration

To support more advanced navigation and future autonomy, planned upgrades include additional onboard sensors. These include a pressure sensor for depth measurement, an IMU for orientation and motion tracking, and a temperature sensor for environmental monitoring. A depth camera or compact underwater imaging module is also being considered to provide visual feedback for tasks such as object following, docking, or mapping. These sensors will provide the data needed to transition from purely operator-driven control to closed-loop behavior.

Autonomy and Programmed Control

As buoyancy control becomes more reliable and sensor inputs become available, the upgraded SeaPerch will support basic autonomous control through programming. The Raspberry Pi provides a flexible environment for Python scripts that can execute predefined maneuvers, depth adjustments, and navigation routines with reduced or no operator input. With access to depth and orientation data, the system will be capable of functions such as depth hold, simple travel patterns, and rule-based responses to sensor readings. This approach provides an accessible introduction to autonomy while keeping the system understandable and instructionally aligned with educational goals.

Conclusion

A long-term goal of this work is to develop curriculum modules that integrate these Seaperch upgrades into K-12 and university-level outreach programs. By incorporating coding, sensor integration, mechanical design, and introductory autonomy, the platform supports a richer and more coherent learning pathway that can scale from early learners to advanced students. As the platform grows, structured lesson plans and project templates will be developed to enable replication and adaptation by other institutions.

Overall, this work shows that SeaPerch can be extended from a one time build activity into a reusable, multi stage learning platform through using a modular upgrade strategy instead of repeatedly purchasing new kits. A standard SeaPerch kit is highly effective for introducing basic underwater robotics, but programs often reach a ceiling once students complete the initial build and driving tasks. Our approach addresses this by keeping the base SeaPerch vehicle as the foundation and adding capabilities through upgrades that can be reused and expanded over multiple camp sessions. Students also enjoy the creative challenges of modifying the physical structure of the vehicles, as well as creating their own underwater obstacle course missions.

In summary, the modular SeaPerch upgrade pathway, starting with onboard computing and now extending to ballast based depth control, creates a sustainable way to grow the program year after year. It strengthens hands-on engineering learning through iterative design and troubleshooting, while also aligning with marine robotics and underwater engineering skill sets that connect directly to real world workforce pathways. Repeated exposure to STEM disciplines encourages students to place themselves at the center of the learning and engage in critical thinking and design aligned to real world applications. These impacts further emphasize the importance of

maximizing opportunities for students and the benefit of implementing SeaPerch as an iterative design process. Given the long-term workforce pipeline development goals of the University of Rhode Island's Engineering Program , these SeaPerch modifications offer cost-effective and engaging content to attract an older and more experienced demographic of summer campers. By demonstrating the iterative engineering design process and continuous improvement, the activities described here are linked to real-world engineering design for naval and maritime applications, where unmanned underwater vehicles are a critical component of current system development and advancement.

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