Charting a Course for a STEM Future

SeaPerch robotics program attracts and challenges young minds

BY PHILIP B. KIMBALL

It was unbearably hot and humid and the noise level was deafening in the Natatorium. The excitement and tension in the air was palpable as screaming team members, families, and friends in the stands cheered on their middle and high school students competing in the 2016 National SeaPerch Challenge held at Louisiana State University in Baton Rouge, LA. Taking place on May 21, this was the sixth, and by far the largest, such national underwater robotic competition, with 196 middle and high school teams from all over the United States, including nine international teams, two of which traveled from as far away as South Australia.

I was a judge on the pool deck, trying to stay focused amid the mind-numbing cacophony while two members of an all-girl high school team from the Southwest maneuvered their SeaPerch robot, or remotely operated vehicle (ROV), the size of a small breadbox, through a five-ring obstacle course with the rings set at random orientation between three and five feet below the pool's surface. This was a timed event with a high degree of difficulty, because the ROV was only slightly smaller than the rings' diameter and because the disturbance of the water's surface and light reflection significantly obscured visibility. Despite these difficulties, the girls successfully completed the course, and as they quickly exited the pool deck, they both were smiling and high-fiving.

All teams competed in two complex underwater events and an engineering poster competition that day for a series of trophies in the three events, and for those teams with the highest point totals in each category, the title of national champion. How did this program become so popular in just eight years and what is fueling its continued expansion today? To understand this popularity and the accompanied rekindling of interest in science and engineering by our next generation of students, we must explore the problem, the driving forces, and how SeaPerch has contributed to an important part of the solution.

Program development

SeaPerch is a K-12 in-school and out-of-school robotics program, sponsored by the Office of Naval Research (ONR), the science and technology arm of the United

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States Navy, and managed by the Association of Unmanned Vehicle Systems International Foundation (AUVSIF). The program trains teachers and group leaders to inspire their students to build their own ROVs following an academic curriculum consistent with national learning standards supporting science, technology, engineering, and mathematics (STEM) subjects with a marine engineering-based theme. Through the construction process, students learn important engineering skills and scientific principles, which, along with problem solving, teamwork and critical thinking, provide for an introduction to potential and rewarding career opportunities in naval architecture, and marine, ocean, and naval engineering.

"With guidance afforded by AUVSIF and with ONR's commitment to SeaPerch, we have grown exponentially, reaching over 350,000 students since 2007," says Susan Nelson, director of SeaPerch. Since its inception, more than 18,000 teachers and mentors have committed to supporting student learning through the program, and to promoting student discovery of STEM subjects leading to increased interest in math and science. The program strives to reach a diverse population, so participants in the national challenge frequently include students from inner cities, rural areas, Native American reservations in Minnesota, and the islands of Hawaii, all of whom have now been introduced to STEM through SeaPerch.

It is well documented that, for decades, the U.S. had been falling behind other nations in math and science scores and in the awarding of engineering degrees. This was synonymous with an alarming decline in the number of students studying STEM subjects. Other countries are catching up fast, and as recently as 2010, the U.S. ranked 40th in the rate of change over the preceding decade, although it was in 6th place in global innovation-based competitiveness.

The navy has long recognized a growing need to replace its graying design and engineering workforce with a healthy scientific, engineering, and technical base of talent. Further, the next generation of jobs, those with the largest growth projections by far, are jobs in STEM-related fields that inspire innovation and the economy that fuels our nation's growth. As a result, top-level attention is being paid to STEM literacy for young people from elementary school through graduate school. Beginning with the National Naval Responsibility in Naval Engineering, the navy STEM strategy includes training, education, and development programs administered by ONR through grants and contracts.

The SeaPerch underwater robot was developed at the Massachusetts Institute of Technology in 2003 based on the book, *Build Your Own Underwater Robot and Other Wet Projects*, by Harry Boehm and Vickie Jensen. Later, through a partnership with the university, Susan Nelson, then director of marketing and educational outreach at SNAME, received a grant from ONR to develop a pilot program. Starting with 750 students in two school districts and with the support of talented and dedicated teachers and mentors, the program grew significantly in popularity within four years. By 2007, it had developed into its current form under the continued administration of SNAME.

Because of this rapid expansion, a support team consisting of a handful of dedicated professionals scattered along the East Coast was formed, effectively collaborating by electronic communication and weekly teleconferences. This same team continues to promote new program startups and assist with district and regional competitions, manage the distribution of

All teams are required to present their vehicles for compliance with the rules and to ensure safe operations.

SeaPerch kits, demonstrate SeaPerch at tradeshows and educational conferences, create Web site content, and organize the National SeaPerch Challenge. Additional program support is provided by a network of the many dedicated navy reservists and personnel from numerous naval warfare centers and research laboratories located around the country.

In 2011, SeaPerch moved to the AUVSIF, where Nelson continued to expand the program, which has been hailed by Secretary of the Navy Ray Mabus as the navy's premier educational outreach program. Here, SeaPerch continues to provide the K-12 component to complement the foundation's more technically advanced competitions for college students. This path to a technical career is known as the "yellow brick road," a term coined by ONR Program Manager Kelly Cooper.

AUVSIF is a non-profit organization that provides students with robotics activities designed to stimulate and sustain their interest in STEM. Its student educational programs include SeaPerch, RoboNation, the Intelligent Ground Vehicle Competition, RoboBoat, RoboSub, the International Aerial Robotics Competition, and the Maritime RobotX Competition.

Teams of two to five

SeaPerch is a hands-on activity where students actually build their own vehicles in teams of two to five. Complete kits, containing all of the components needed to build a vehicle as well as tool bags containing the necessary hand and power tools, are available through the SeaPerch Web site. The actual build is facilitated by the illustrated step-by-step build manual and supplemented by PowerPoint files and videos of more challenging portions of the construction. The build may be completed in as little as a day; or, for teachers using the enhanced curriculum to emphasize the scientific and engineering principles through classroom lessons, as long as a school semester. Students cut and assemble the PVC pipe frame, and carefully waterproof and mount their three 12-volt DC motors, two horizontal axis shafts, and one vertical axis shaft. Then they make more than 40 wiring and soldering connections, both on the frame and in their controllers, which is a switchbox that provides forward and reverse power to the motors through the 40-ft., flexible CAT5 cable.

For the Engineering Poster Judging, all teams prepare a poster showing their journey with the build, and how they solved problems.

Once construction is complete, the students verify their vehicle's system functionality by testing switch positions with propeller rotation; balancing their vehicles for transverse and longitudinal stability; and adjusting for near neutral stability by varying the amount of foam flotation to offset the vehicle's weight. Then they are ready for the "wow" moment when they first start "flying" their vehicle in six-degrees-of-freedom under water. Students who are familiar with video games have no trouble mastering the remote controls of a SeaPerch, and soon they are ready to compete against their peers in local and regional competitions.

Learning how to work as a team and overcoming obstacles during the build, such as troubleshooting poorly soldered joints, leaking motors, and non-secure propellers, lead to the documentation of these challenges and their resolutions through an illustrated engineering poster. Here, the students present their build philosophy and their journey from first opening the kit box to the thrill of successfully driving their SeaPerch in peer competitions. Complex underwater events and the engineering poster are required in most competitions, and the excitement, confidence, and sense of involvement and accomplishment gained by the students last a lifetime.

Susan Nelson, director of SeaPerch, with a competitor at the 2016 National SeaPerch Challenge.

One student's story

Nathan Hagan, a SNAME member who knows SeaPerch well, was first introduced to the program as a senior in high school, where he was immersed in the planning and design of the inaugural 2009 Northern Virginia regional competition. His involvement at that time was driven by his interest in underwater ROVs. Following this event, he was asked to speak about his experience and perspective as a student at the first ever SeaPerch Stakeholders Meeting in Hawaii. "Aside from it being an amazing travel opportunity, it was a great chance to network and represent my community," says Hagan of

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that conference. After graduating from high school, he chose to study naval architecture and marine engineering at Webb Institute. He says that SeaPerch exposed him in high school to the community that was SNAME, and so he quickly became engaged in SNAME leadership at Webb. In this leadership role, he enthusiastically organized a competition event at Webb as a STEM outreach effort for the surrounding community.

Hagan's involvement in SNAME continued to grow, and in his junior year he became chair of the Student Steering Committee. In this role, he encouraged maritime colleges and universities around the world to establish their own SeaPerch STEM events, which proved to bring the students closer together while encouraging a future generation of maritime professionals. While attending Webb, he gained a better understanding of the marine field that influenced his selection of a career. He is now employed at the Naval Surface Warfare Center in Bethesda, MD, and readily admits that his involvement with SeaPerch helped encourage him to stay active in the role as the lead for various STEM outreach programs, including currently serving as a mentor to SeaPerch teams in the community. He adds that SeaPerch drew him to ROVs as his prime interest as a naval architect, and that his selection as a SMART Scholarship recipient while at Webb was most influential in the landing of his current position today as a naval architect in ship structural design.

Competitors at the pool operate their vehicles through two underwater events.

Innovations and challenges

For some time now, students have used underwater cameras attached to their ROVs with monitors on the surface. For instance, in a pool where the water's disturbed surface can impede the ROV operator's ability to see four to six feet down, or on the bottom, the camera can, when allowed, be helpful in maneuvering through the underwater challenge events. They have been used to record and stream observations of bottom composition and aquatic life in the shallow waters of oceans, lakes, and ponds. I remember a conference, just a few years ago, where students demonstrated how they could drive their SeaPerch units over the coral reefs in Hawaii and stream the video feed to classrooms in Minnesota where the students were studying the subject. Modifications in common use today include articulated arms and mechanical gathering devices, or scoops, and multiple motors. A number of teams at the 2016 National Challenge impressed us by pointing out some of the three-dimensional (3D) plastic parts they had printed for their ROVs.

For the next step in STEM education, discovery and invention, SeaPerch is developing two new innovations—a data gathering module and a virtual SeaPerch.

Data gathering module. Soon to be introduced is a self-contained data gathering module, housed in a small waterproof box that will be carried onboard the ROV and outfitted with a variety of sensors to gather data during underwater surveys in students' local waterways. A MicroSD card for recording such parameters as temperature, pressure, conductivity, heading, and light (turbidity) can be used. An independently powered real time clock for time stamping and a Bluetooth module for on-the-surface transmission will enable sensor checks and data downloads.

Students will be able to analyze the data over selected time periods to detect trends and formulate conclusions. The results might spark further exploration and research direction. An added benefit could be the crowdsourcing of the data, where sharing with others in the nationwide SeaPerch network will form bonds of like interests, stimulate creativity, increase learning skills, and open minds to new ideas.

A good example of how this student research could be put to immediate use involves the effects of global climate change. Warmer surface temperatures, combined with increased sunlight and phosphorous in fresh water bodies around the country and the world, have created an environment for development both of invasive species and toxic cyanobacteria that produce toxins endangering humans as well as terrestrial and aquatic wildlife.

Student research projects could include adding sensors to their data gathering modules to measure such parameters as dissolved oxygen, pH, and chlorophyll pigment levels. The United States Environmental Protection Agency has started a cyanobacteria monitoring and bloom watch, or "CyanoWatch" program for greater New England, but clearly this will be expanded nationwide before long. Students could function as "citizen scientists," and would soon be able to transmit their collected data via smart phone apps, thus

providing real contributions to the effort to mitigate these harmful toxins.

Virtual SeaPerch. In an effort to push the boundaries of technical innovation and create continuing challenges for more advanced and inquisitive students, one concept being considered uses the SeaPerch to teach 3D modeling. A concept called Virtual SeaPerch, or V-Perch, is an experimental 3D modeling training program designed to complement the existing SeaPerch model. Applying coding and computer science using SolidWorks 3D for computer-aided design (CAD)-based design and simulation testing of virtual ROVs, students without ready access to water can still experience the benefits of the SeaPerch curriculum and activities, which would further increase the program's reach.

This program would provide a platform for students to learn and practice CAD and simulation testing that mimics real-world engineering design practices, enables low-investment design innovation, and is especially beneficial for students with no (or limited) access to bodies of water in which to test their ROVs. Students can experiment with the design of their own underwater ROV by modifying and manipulating parts, designing and adding new parts and changing materials. These ROVs can be virtually launched through flow simulations where students can analyze buoyancy and movement in the water. Using SolidWorks, the project provides a base on which to build transferrable skills by applying and validating science and engineering concepts.

Paying it forward

Currently, there are in excess of 1,000 active SeaPerch programs, both school and groups including Boy Scouts, Girl Scouts, robotics clubs, 4-H camps, the Navy League and many others, with at least one program in every state and Puerto Rico and in ten countries. This creates a unique opportunity for SNAME to participate in the SeaPerch program with its members and sections located throughout the U.S. and in a number of other countries.

Individual members and local sections can participate directly in the SeaPerch program and pay forward in three meaningful ways: one, by becoming an individual coach or mentor to a student team in your area; two, by the local section hosting a new startup SeaPerch program locally; and/or three, by the local section participating in the National SeaPerch Challenge.

In terms of tools for assistance and guidance, the SeaPerch Web site is filled with useful information about building

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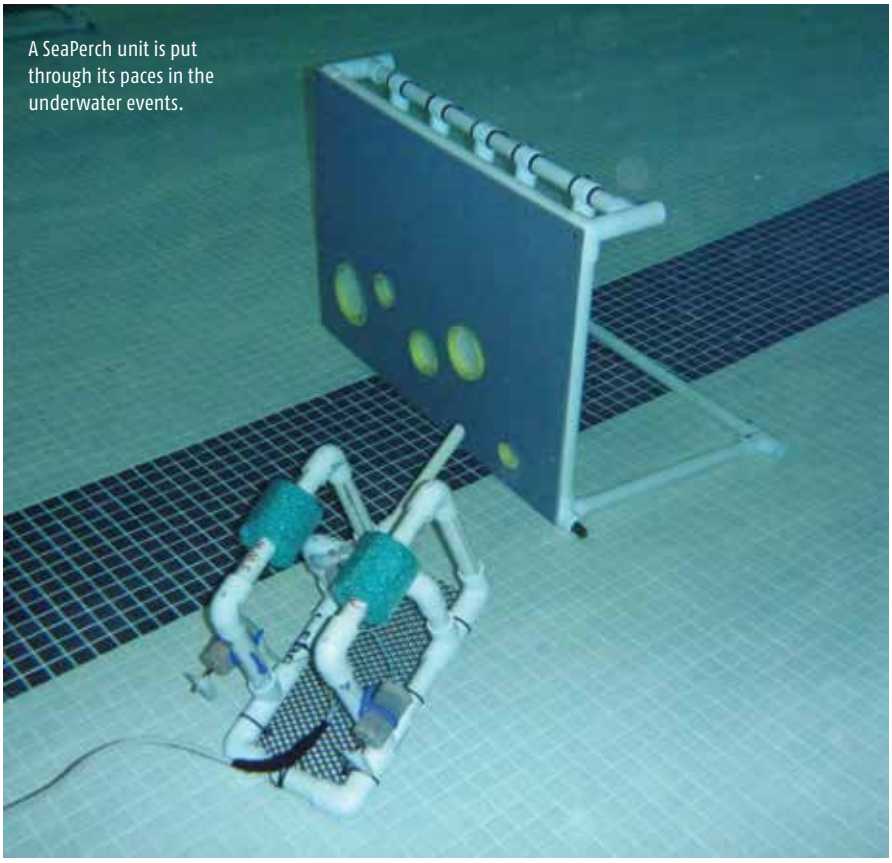
the ROVs, the science and engineering behind the design, starting programs, running competition events, and much more. Most notable for members would be two downloadable documents: the Build Manual and the Resource and Activity Guide. The Build Manual is a detailed step-by-step illustrated guide to building the ROV. The Resource and Activity Guide is a framework of descriptions and activities to assist groups in understanding the mission and opportunities of the SeaPerch program. This includes an overview of how to start a program, suggestions for managing a competition, and the connections between the technologies and potential careers. Additionally, there is a sampling of full science lessons with their related core standards available to teachers and mentors to use during the students' assembly of each segment of the ROV. Supplemental PowerPoint presentations are available, including design challenges, the electrical system, the mechanical system, and core technologies.

SNAME members can search out a program in their area and volunteer their expertise to help students understand the science behind the robot's functionality, supplementing the theory and providing real life stories based on their career experience to inform and inspire inquisitiveness and innovation, and to further experimentation.

For members interested in starting new SeaPerch programs in their local area, here are some suggestions to get started:

- visit the SeaPerch Web site and learn about the program and its many benefits for students and adults alike
- invite science teachers/after school program leaders from a local SeaPerch program to attend a section meeting and give an overview of their robotics program, and its challenges and results
- invite someone involved on the National SeaPerch Team to present an overview of the program's rapid development across the country to interested teachers and leaders in your community
- discuss the concept at your next executive committee meeting, obtain full backing from the committee, then promote it within the section by making presentations at section meetings, by forming a proactive committee and building interest among members through the section's Web site, Facebook, e-mail, and other social media
- sponsor trophies, tee shirts, and accessories for local and regional SeaPerch competitions
- organize member-volunteers to provide mentoring and coaching, leveraging their talents and engineering skills for local teams and to assist with organizing, finding sponsors, registration, and judging at local events.



A SeaPerch unit is put through its paces in the underwater events.

For those be interested in supporting the National SeaPerch Challenge, here are some ways in which section members can make a difference:

- sponsor the travel of a team from a new or established SeaPerch program in your area to the National Challenge
- adopt a team and follow its preparations for travel to Nationals, and post its results via social media
- partner with another section to sponsor the travel of more than one team to nationals
- mount fundraising campaigns, and/or solicit supplemental sponsorship funding by reaching out to local businesses to support team travel
- sponsor promotional gear and accessories for students
- recruit qualified judges and volunteers to assist on competition day.

There are numerous other ways in which members and sections can participate and pay forward. The experience of working with our next generation of scientists and engineers will last a lifetime and the rewards of paying forward are immeasurable.

One member's story

In mid-2015, SNAME Past President Bruce Rosenblatt contacted Susan Nelson about starting a SeaPerch program in the Cayman Islands. Rosenblatt was

acquainted with another resident of the islands, a relative of a prominent Greek shipowning family, whose dream was to create a renewed awareness of the Cayman's strong seafaring traditions and to revitalize its maritime professions, and, knowing Rosenblatt's connections to the industry, asked for his help.

Nelson responded by organizing a two-day seminar in September that introduced more than 260 secondary school students and teachers to this unique program. Over the two days, through a spirited presentation by Nelson and a hands-on operation of the ROVs by all in the hotel's pool, and, later, an opportunity for the students to actually assemble segments of the robotic vehicles, a significant level of enthusiasm was generated. Spearheaded by Sherice Arman, an admiralty attorney on the island and president of the Women's International Shipping and Trading Association, the program was jumpstarted with organizational and financial support from her firm and other sponsors to fund ROV kits. The next step was the training of teachers in January 2016, a session conducted by Naval Surface Warfare Center Electrical Engineer, Bill Porter. Ten teachers, along with a number of student observers, actually built their own vehicles and operated them in a local pool, all in preparation for conducting SeaPerch builds in their individual classrooms.

The first Cayman Islands SeaPerch Challenge was successfully held in March 2016, with ten student teams from seven schools competing for the opportunity to represent the Caymans at the 2016 National SeaPerch Challenge. I recall happily welcoming the BOLTS to Nationals, the Cayman's winning five-member team, when I was volunteering as part of the compliance team, the process in which every SeaPerch entry is examined to ensure both conformance to the rules and safe operation.

Based on the resounding success of the Cayman SeaPerch initiative, Rosenblatt was pleased to report that a yearly forum with an educational segment, focused on the SeaPerch and STEM, had been formed, the first of which was held in October 2016.

Measuring success

We've learned here about two measures of the program's success with a student's story and a member's story. With the rapid expansion of the program over the last eight years, there are trends and outcomes that can help us determine if students have been inspired by SeaPerch and now plan both to continue their studies in science and engineering and to pursue careers in STEM-related professions.

A 2014 report, resulting from the gathering of data, analytics, and assessments by ThotWave Technologies, consultants to SeaPerch, documented some of the innovations and applied research projects created by students, examples of which include:

- used CAD/3D printing for design and implementation of motor housings and other parts
- implemented a secondary system for retrofitting articulated arms, vacuum suction implements, and retrieval hooks
- created a custom camera mount using a 3D printer
- researched the Great Pacific Garbage Patch, then designed and mounted a device to remove trash from surface water
- studied solar power and conducted a feasibility study of a solar-powered SeaPerch
- researched the environmental issues facing the grass flats and scallop beds in the Gulf of Mexico
- studied underwater archeology and used a SeaPerch to capture images from inside a ship that sunk in a hurricane
- conducted research that resulted in a student group presentation on a modified vehicle to meet the objective of functioning in a fire-related disaster.

More than 19,000 post-program assessments and evaluations have been gathered from students. Student comments about the program included, "it increased my confidence in my ability to participate in engineering projects;" "it made me more confident in my ability to succeed in engineering;" "it made me decide to take different classes in school such as science and math;" and "it made me decide to work harder in school."

SeaPerch has opened the eyes of thousands of students to the possibilities of STEM-related study and careers in their futures. But what of the way forward for SeaPerch? It is anticipated that growth will continue in the U.S. and that there will be increased growth internationally. In addition, curriculum enhancements will continue to be developed to enrich the experience both of teachers and students, and technical developments such as the data collection module, the Virtual SeaPerch, and programmable, autonomous vehicles will continue to inspire active minds.

After the day's competitions had concluded at the 2016 National Challenge, I ran into the two girls I had judged for the obstacle course part of the competition. They were bubbling over with enthusiasm and pride that they had done so well, and asked me if they could meet the founder of SeaPerch. I thought for a second, and looked around wondering if I could find this person among the 1,800 people in the field house. I took off with the two students in tow, eventually finding Susan Nelson engaged in conversation with another group. When she was able to break away, the girls stepped up and asked her if they could shake her hand, declaring, "You are the reason we are becoming engineers!" **MT**

Philip B. Kimball *is the former executive director of SNAME.*

Deeper Dive

To learn more about the programs and work covered in this article, check out the following resources.

The SeaPerch Web site is at www.seaperch.org.

AUVSIF, www.auvsifoundation.org, is a non-profit organization that provides students with robotics activities designed to stimulate and sustain their interest in STEM.