Effective Strategies for Generating Awareness and Interest in Science and Engineering among Underrepresented Youth

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Abstract

Native Americans are seriously underrepresented in science and engineering. To address this concern, the authors have created a flexible two-component workshop that uses submarines and submersibles as a vessel to introduce basic science and engineering concepts.

Submarines must resist considerable pressures, resist corrosion, be able to move in three dimensions while mostly navigating blindly, and be able to support life for months at a time. Science and engineering basics that are needed to address those concerns are introduced and explained in the workshop, such as pressure and strength, controls, environment, and product development.

One component of the workshop is lectures that incorporate electronic slides and short videos, where each short video demonstrates a concept. For example, one video shows how inflated balloons shrink when submerged, due to the water pressure increasing at depth. Another video shows animations of how submarines are able to move in three dimensions under water.

The other component of the workshop is hands-on activities. The hands-on activities start with letting participants control a remote-controlled submarine in a swimming pool. Next, the participants assemble tethered remotely-operated submersibles according to a fixed design from pre-made kits. Finally, a design challenge with a scored competition at the end is conducted, where participants receive a large collection of parts to build their own design of tethered remote-operated submersible. The competition consists of several timed navigation challenges, such as traversing a portion of the pool while the submersible remains submerged the entire time.

The workshop has been given to groups of Native American middle- and high school students five times in two states, South Dakota and North Dakota, and is about to be given to a small group of incarcerated youth at a local juvenile detention center, the Western South Dakota Juvenile Services Center. Written surveys are given before and after the workshops, and qualitative results consistently show a large increase in the participants' interest in pursuing careers in science and engineering.

Introduction

Native Americans / American Indians are seriously underrepresented in science and engineering. As a way to address this concern the authors have developed a two-component workshop using submarines and submersibles as a vessel to introduce and generate interest in basic science and engineering concepts.

Submarines and submersibles were chosen because they incorporate various science and engineering concepts that students at many levels can relate to, such as buoyancy, propulsion, controls, dynamics, pressure and strength, environmental aspects like corrosion, and life-critical systems. Submarines have also figured prominently in popular culture, and fundamental awareness of their existence, along with some conceptions of how they operate, can be found in most locales.

This work also ties in with a wider recognition that there is a need for changes in the way STEM topics are taught [1,2], in particular in increasing student involvement in their learning. Research on active learning has shown great benefits from this to student engagement, learning, and retention, compared with traditional lecture-based approaches [3-7].

However, research has also found that there are obstacles that prevent faculty from fully implementing research-based teaching practices [8]. For one, there is both a learning curve and a time cost involved in developing active learning activities. Some faculty members feel that this cost outweighs potential benefits to the students. Additionally, most faculty are practitioners of pedagogy, not researchers or theoreticians thereof, and are thus primarily interested in knowing what is most effective in the classroom, but not necessarily in why a given technique is effective.

The initial experiences described here are part of an ongoing effort to develop and provide relevant and easy-to-implement engineering teaching tools that use complex engineering systems as a way to attract the attention of the students. With these, fundamental engineering concepts can be introduced into the classroom with minimal extra effort by the classroom practitioner. In addition, since they are provided in the context of a submarine, the practical relevance of the topics covered can be readily demonstrated by the instructor. A major goal of the effort described here is to introduce fundamental STEM topics to underrepresented groups, and to generate awareness of and interest in careers in STEM fields in the same groups. Results from initial implementations show a marked increase in participants' interest in considering STEM careers.

Strategy and Pedagogy

The long-term strategy to generate awareness of and interest in science and engineering consists of first generating and giving workshops that convey basic science and engineering concepts in an engaging manner. These initial workshops are given by the developers. As a next step, teachers and other interested parties that want to give such workshops are given a package with training materials for themselves and students, so that they can give these workshops to students with minimal effort outside of the workshop itself. In this way, a much larger audience can be reached. Furthermore, it is hoped that workshop attendees talk to their peers at home about these activities and perhaps garner interest for more workshops. Students that otherwise had not considered STEM careers might enroll in such programs, and this in turn could generate more interest in STEM fields among their peers and their juniors. This paper describes the authors' experience in the development and implementation of one such workshop.

The pedagogy used in these workshops is to present individual scientific and engineering concepts with immediate hands-on reinforcement. In addition, each concept is presented in the context of an overarching complex system. This accommodates students that identify with different 'learning styles'. The connection to a complex system provides a way for students to see meaningful applications of basic concepts that might otherwise seem disconnected from their world view and world experience. In addition, seeing that a complex system can be broken into simpler parts that can be explored individually provides a sense of mastery to the student, and can reduce the intimidation that might be otherwise felt when presented with any complex system.

Current Implementation

The approach taken here was to develop a workshop that employed a module-based teaching methodology to present fundamental concepts within buoyancy, control, pressure, structural strength, environmental considerations, and product development. In addition, students were involved in hands-on demonstrations to actively reinforce the theoretical concepts. The workshop also included a competition held at the end, where students were divided into groups to design and build remotely operated submersibles and compete with these against each other in a skills challenge. The rules for this competition provided to the students along with a list of the parts given to each team is provided in Appendix A.

This workshop focused on submarines and submersibles because they embody many engineering concepts. Submarines must withstand significant repeated pressures under water, while maintaining normal pressure on the inside and without material fatigue setting in. They have to withstand corrosion on both the inside and outside. They must maintain reasonable air temperatures and sustain an atmosphere compatible with life on the inside. They have to be able to make controlled movement in three dimensions, and continuously keep track of their position as they do so. Finally, to make a submarine that does these things well requires not just sound engineering, but also well-thought out plans for design and manufacture.

One workshop component was lecture based, while the second component consisted of hands-on activities where the lecture material was applied by the workshop participants. The lectures were interactive and included electronic slides as well as short videos to introduce and illustrate key concepts. Each concept was then discussed with the participants, and then expounded upon with relevant equations and example calculations. This was then followed up with the second component; hands-on activities.

An overarching theme of the workshop was a larger competition at the end, which the students were informed of the first day: They would have to design and build their own remotely operated submersible vehicle (ROV), connected to the controller with a tether, and then use that ROV to complete several tasks in the shortest time. This was the main event of the workshop, and proved both engaging and popular. This competition forced students to consider the placement of buoyancy devices and drive motors, as well as the overall structure of the ROV.

This workshop was given during the summer of 2013 to four different ‘cohorts’ of the South Dakota GEAR-UP program held on the South Dakota School of Mines and Technology (SDSM&T) campus, and also to students participating in a summer science camp at the United Tribes Technical College (UTTC) in Bismarck, ND. GEAR-UP is a US Department of Education sponsored program, designed to increase the number of low-income students who are prepared to enter and succeed in postsecondary education [9]. The UTTC summer camp has similar goals, but is an initiative local to UTTC. The vast majority of the workshop participants identified themselves as Native American / American Indian.

The workshop consisted of the five units described below.

Unit 1 provided an overview of the working principles and the history of submarines and submersibles, and also the different roles they can play. Some short videos describing life aboard US NAVY submarines were shown to demonstrate how they can be self-sufficient and maintain life under very challenging conditions. The differences between military, research, and tourist submarines were outlined. Research submarines can go far deeper than other submarines, but have very limited room and endurance. Tourist submarines have room for passengers, along with large viewports to see outside, but have little endurance and cannot travel very deep. Military submarines have the most endurance and can travel deep enough to hide from most other vessels. The hands-on part was then introduced, which was to operate a commercially available radio-controlled scale submarine, the “Neptune” shown below in Figure 1, in a swimming pool. Among others, this activity allowed the participants to experience first-hand the difference between static and dynamic diving.

Figure 1: "Neptune" radio-controlled submarine

Unit 2 introduced the fundamentals of buoyancy and control. Among others, the following questions were posed to the class: “How do things float?” and “What are some things that float naturally?” The concepts of buoyancy and density were thus introduced. Short videos explaining Archimedes’ principle, density, buoyancy, together with center of mass and center of buoyancy were shown. A brief class discussion was held, and example calculations were shown, such as the relationship between displacement and how much weight a boat can hold and remain afloat. The concepts of motion control, navigation, and how they tie together were also introduced. Students were asked how they might be able to walk out of the classroom with their eyes closed. GPS and inertial navigation, and their combined use were explained. The hands-on part was then introduced in the form of a short “tin foil boat” competition: The attendees were divided into small teams to design and make a tin-foil boat that could hold the most machine-screw nuts. These tin-foil boats were then tested in a fish tank in the classroom, and the boat that held the most nuts was declared the winner.

Unit 3 introduced the environmental aspects surrounding the operation of and life on board a submarine. Military submarines can remain submerged for weeks on end, and so there is a need to maintain a breathable atmosphere and acceptable temperatures and humidity during that time. Corrosion is another key challenge, as the ocean presents a highly corrosive environment with the constant presence of salt, moisture, and oxygen. Potable water must be available, as well as sanitary facilities. The hands-on activity for this unit was to assemble the Mini-ROV shown in Figure 2 according to set plans, and then test it in the swimming pool, as shown in Figure 3.

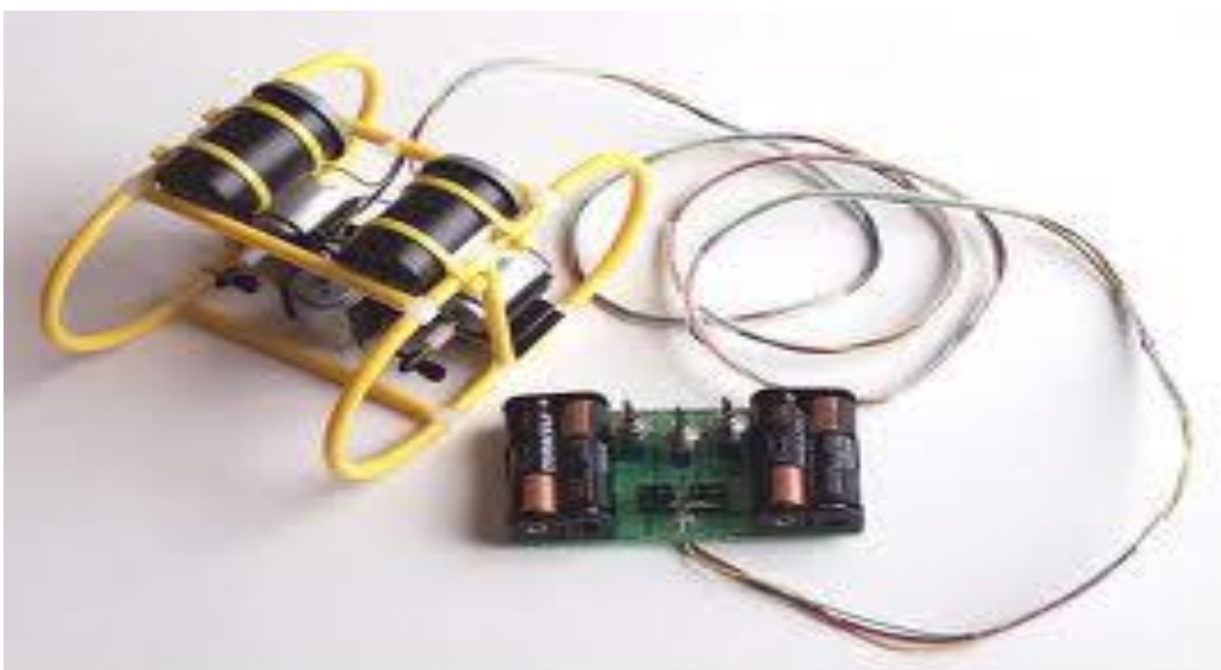

Figure 2: Assembled Mini-ROV used in workshop (Source: http://www.apogeekits.com/images/ROV.jpg)

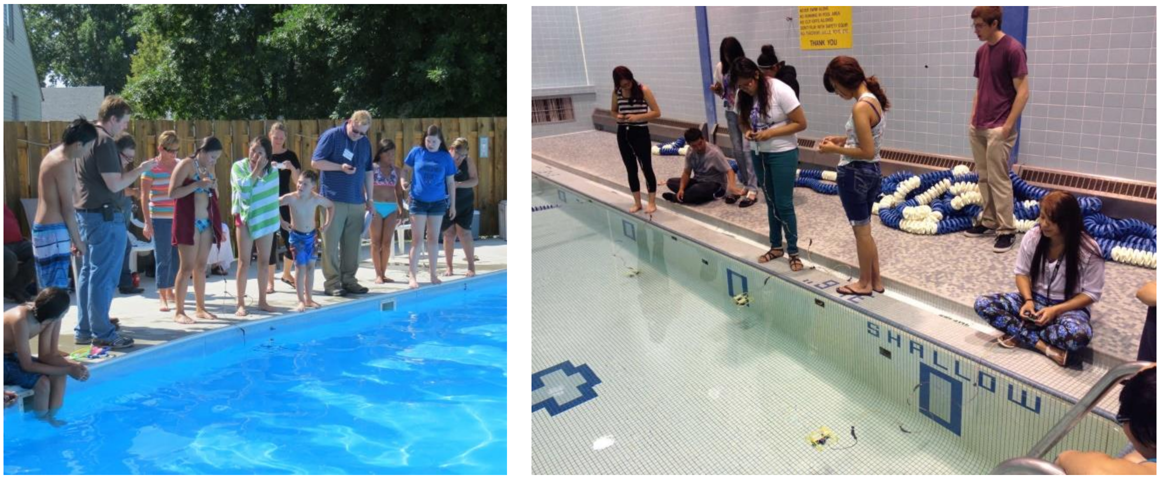

Figure 3: Workshop participants testing mini-ROVs at the UTTC summer camp (left) and the SD GEAR UP program (right)

Unit 4 covered pressure and structural strength. Brief videos demonstrating the effect of water pressure, and how it varies with depth, were shown. One video showed the collapse of a flat-sided container as it was submerged; another showed how the diameter of an inflated balloon decreased with increasing water depth, and then returned to original upon surfacing. There were then discussions on how to resist this water pressure when designing a submarine while maintaining atmospheric pressure inside. Different hull shapes were shown, in particular the spherical pressure hull for deep ocean research submarines, versus the more cylindrical shape for military submarines that cannot go as deep but can hold more crew and equipment. The competition details were announced at the latter part of this unit, and the students were given a list of parts available to them (see Appendix A). They were then asked to individually come up with concepts for an ROV made from the parts given.

Unit 5 covered product development. Discussions were held on what constitutes a “successful” product or design, and what methods are used for product development by companies that are consistently successful. Common reasons for product successes and failure were discussed, along with specific examples (such as the original VW “Beetle”). A generic product development process was introduced, and a discussion was held on the different complexity levels of different products, such as lawn mowers, smartphones, and cars. The students were then placed in groups and asked to compare their individual ROV design ideas and come up with a group design, which they were then asked to build. Finally the ROV competition was held at a local swimming pool.

Results and Discussion

The participants came up with a variety of ROV designs, all built from the same parts kits, a few of which can be seen in Figure 4, while Figure 5 shows one of the ROVs that was designed and built by participants during one of the competition tasks.

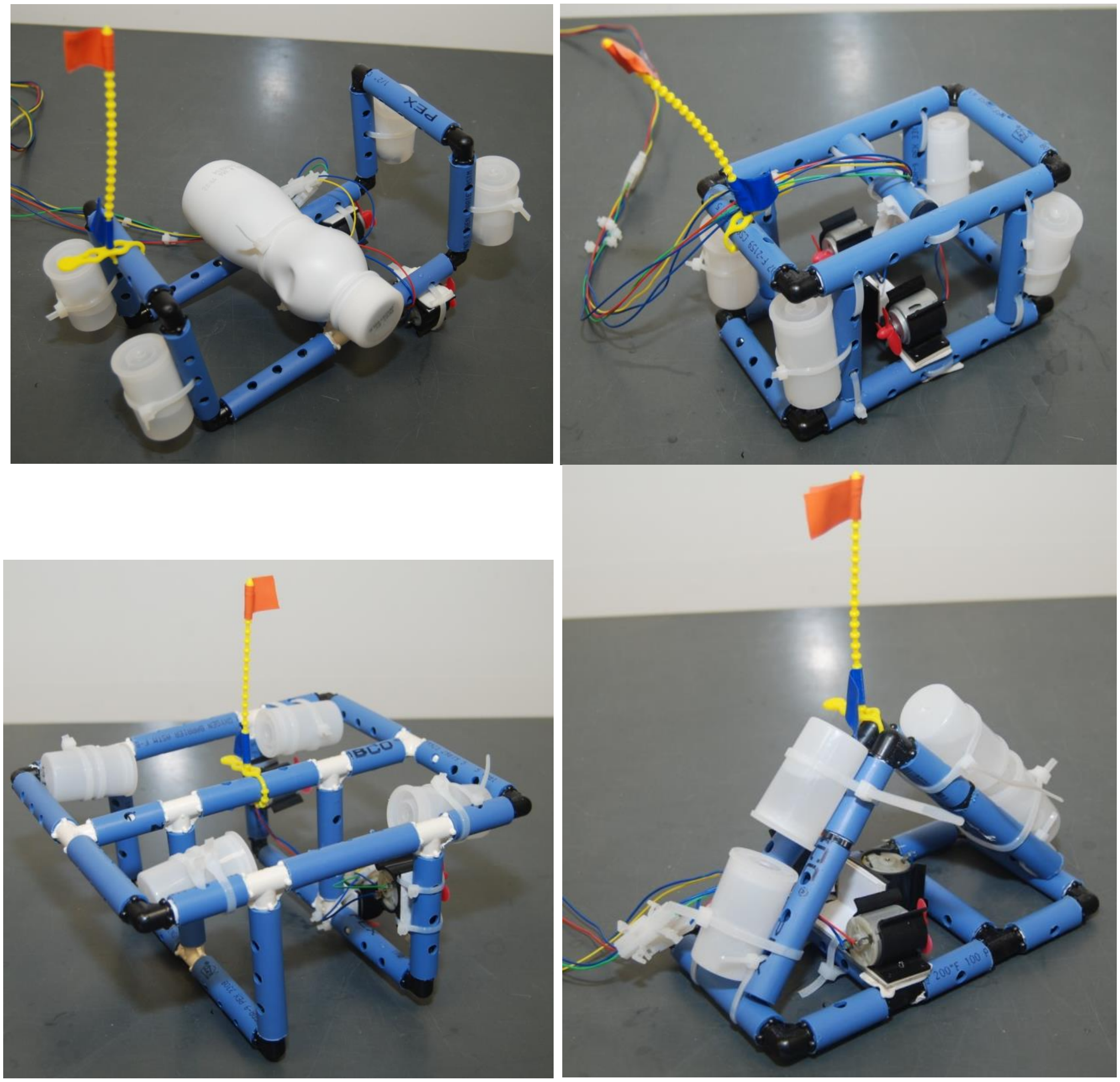

Figure 4: Some ROV designs by workshop participants

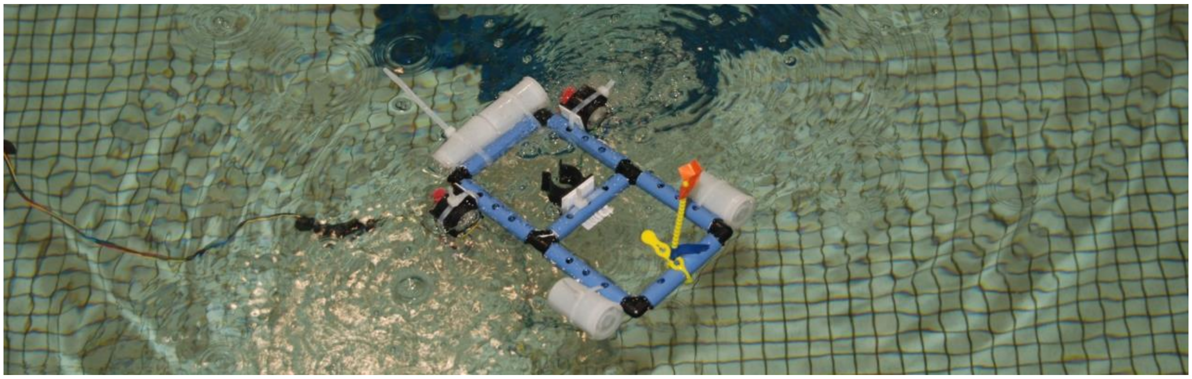

Figure 5: A participant-designed and built ROV under way in competition.

Surveys were given before and after each workshop, and salient results are summarized in Figures 6 through 9.

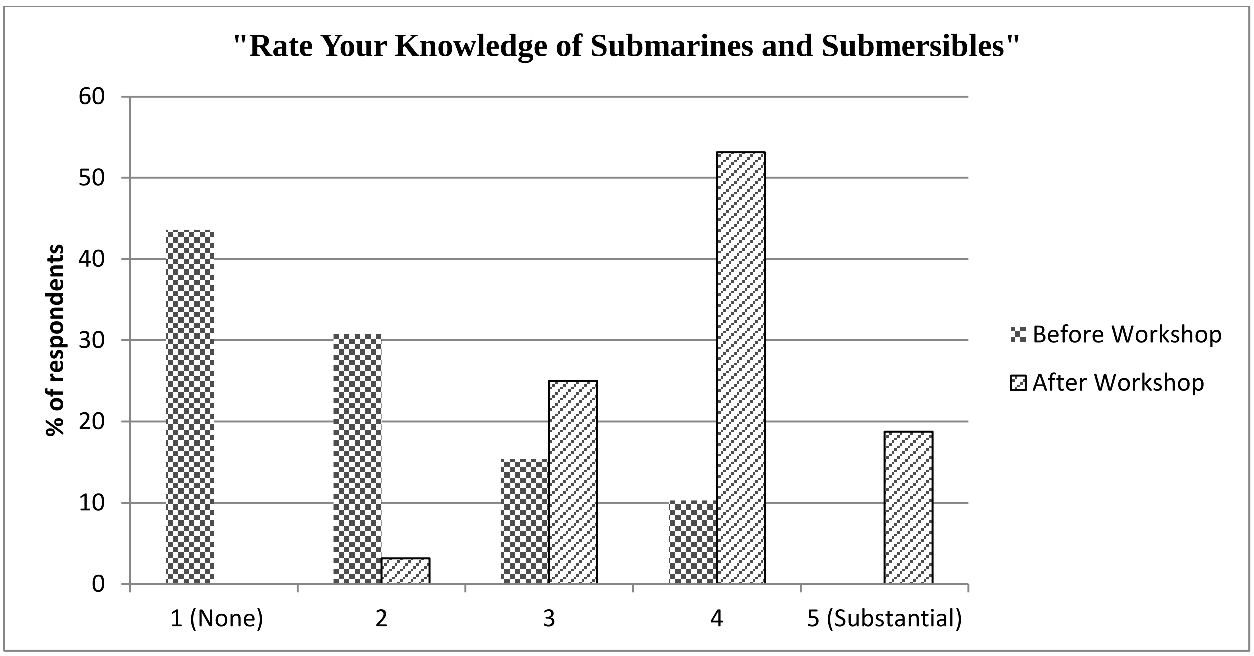

Figure 6: Workshop participants' self-rated knowledge of submarines and submersibles before and after workshop

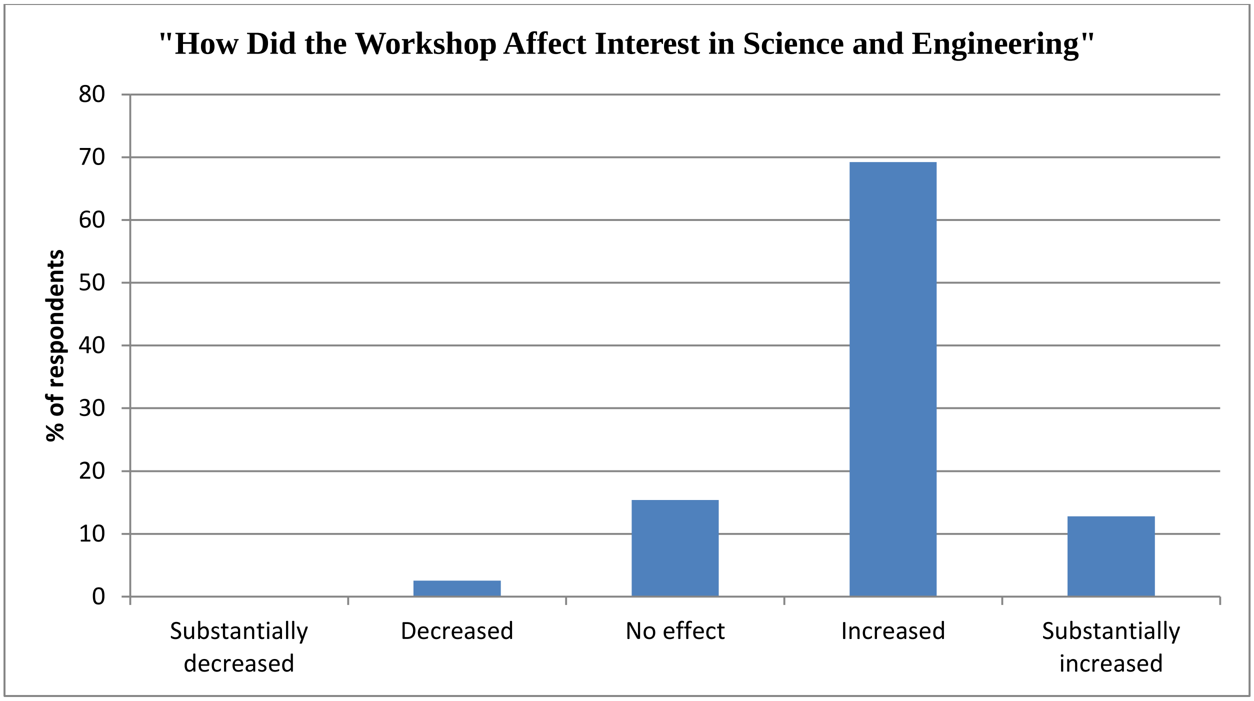

Figure 7: Effect of workshop on participants' interest in science and engineering

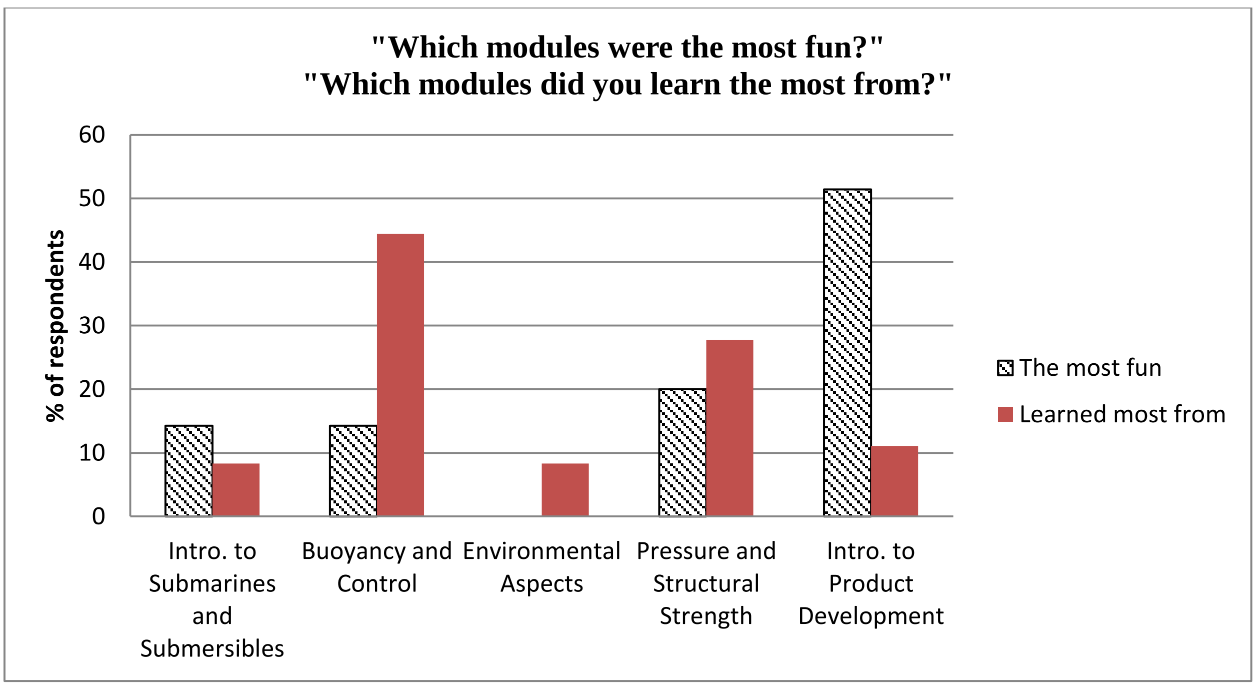

Figure 8: Which topics did the participants enjoy the most, and which did they feel they learned the most from.

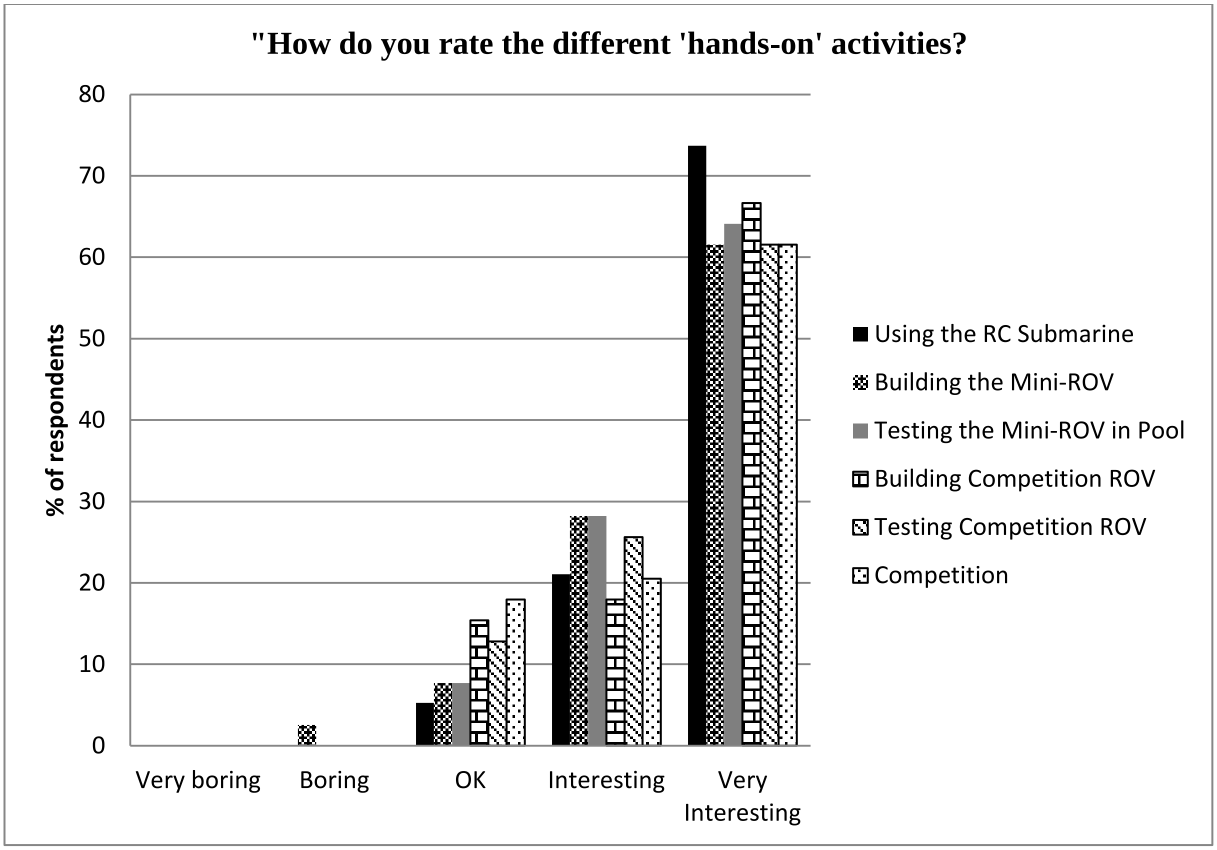

Figure 9: Participants' rating of the hands-on activities

The participants indicated that the workshop increased their knowledge of submarines and submersibles, and more critically, over 80% of the participants indicated that the workshop had increased or substantially increased their interest in science and engineering. They thought the "Introduction to Product Development" unit was the most fun, while they felt they learned the most from the "Buoyancy and Control" unit. The hands-on activities were very well received; the majority of participants rated all of them "interesting" or "very interesting".

A number of valuable lessons were learned during the implementation of the workshop:

- Clear behavioral rules need to be established at the beginning of the workshop, such as no use of electronic devices, no disruptive behavior, etc.
- If possible, someone other than the workshop instructor should be enforcing classroom discipline.
- Young audiences tend to stay up too late at night, and can be very tired in the mornings. Workshops are thus best offered a little later in the day.
- For the same reason, lights in the classroom should never be turned completely off.
- US Customary units are understood better than SI.

- Having immediate access to a ‘test facility’ for the participant-designed ROVs is important. This does not have to be a swimming pool; a large fish tank will work for most purposes.
- It is important to have a ready supply of spares for parts that cannot be easily or quickly repaired

Conclusions and Future Work

The results from pre- and post-workshop surveys consistently showed a marked increase in the awareness and interest in science and engineering among the participants. Hands-on activities rated highly; the competitive aspect received some mixed reactions, but found favor overall. The negative comments centered around intimidation from the competitive aspect.

Thus, the workshop format as described in this paper is working well for increasing awareness and interest in science and engineering, and will be pursued further.

For the future, a faculty member at UTTC plans to offer the module on her own and a local high-school teacher in Rapid City, South Dakota, has expressed interest in giving the workshop in the context of a Physics class. In addition, a local juvenile detention facility (jail), the Western South Dakota Juvenile Services Center has expressed interest in the workshop, which in the first instance will be given by the developers to a small group of participants.

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Appendix A: Rules and instructions for final design competition:

- Your team must build a remote operated vehicle (ROV) given the following parts:

  - 30 x 1 ½" pipe with holes
  - 30 x 3" pipe with holes
  - 10 x 6" pipe with holes
  - 4 x 3" pipe without holes
  - 4 x 6" pipe without holes
  - 20 x T-joints
  - 10 x straight joints
  - 20 x elbow joints
  - 10 x end caps
  - 4 x canisters
  - 2 x medium bottles
  - 1 x 2' chain
  - 50 x 8" zip ties
  - 50 x 6" zip ties
  - 12 x weights
  - 3 motors, long harness, and controller
  - 2 x sponge
  - 10 x 1" pieces of sticky tape
  - 1 yellow competition flag

- The competition will consist of 3 different tasks. You will be allowed 2 trials in each task, and your best time will count towards your final score. In each task, points will be distributed to each team as follows:
  - completion of the task with the fastest time = 4 points
  - completion of the task = 2 points
  - no completion = 0 points

<u>Task 1</u>

Your ROV must start at the surface of the water, submerge to touch the floor of the pool, and surface again.

<u>Task 2</u>

With your ROV at the surface of the water (blue flag marker remains <u>above</u> the surface of the water), you must navigate a predetermined length of the pool and return to the start line. Failure of the flag marker to remain <u>above</u> the surface of the water will result in a "no completion" score.

Task 3

With your ROV submerged (orange flag marker remains below the surface of the water), you must navigate a predetermined length of the pool and return to the start line. Failure of the flag marker to remain below the surface of the water will result in a "no completion" score.

COMPETITION RULES

- Each trial must be completed by a single team member.
- Each team member must drive the ROV at least once during the competition.
- No adjustments can be made to your ROV after the competition starts.
- No dragging your ROV by the wire harness.
- You may not touch your ROV during a trial.
- No obstructing the drivers during a trial.
- You will have 3 minutes maximum for each trial.
- The judges have the final determination in the competition.

See Figure A1 for pictures of the different part types.

Figure A1: Pictures of the different part types provided for ROV design competition