Title: Using underwater robotics in the engineering classroom

Authors: Rustam Stolkin, Liesl Hotaling, Richard Sheryll.

Affiliation: Stevens Institute of Technology

Abstract

Underwater robotics projects offer an excellent medium for discovery based engineering and science learning. The challenge of building underwater robotic vehicles and manipulators engages and stimulates students while encompassing a broad spectrum of engineering disciplines and scientific concepts.

This paper describes an ongoing effort, at Stevens Institute of Technology, to incorporate such projects into the engineering curriculum. We report the successful design and implementation of student projects, building wire guided remotely operated underwater vehicles (ROVs) with motorized grabbers. We also describe ongoing work to extend these projects to include computer control and sensory feedback, allowing students to develop autonomous underwater vehicles (AUVs). The effectiveness of these modules for teaching fundamental engineering skills will be independently assessed in accordance with established educational theory.

Introduction

There is an ongoing effort at Stevens Institute of Technology to develop a set of educational modules, which will teach fundamental engineering principles through the design, construction, programming and testing of underwater robotic vehicles, using a combination of LEGO and additional materials. These modules will emphasize discovery based learning and collaborative team work, and will give students practical experience of the iterative engineering design process.

This paper provides an overview of the proposed educational module, and presents the results of a pilot implementation project during which students successfully constructed remotely operated underwater vehicles.

Why build underwater robotic vehicles?
When students design, build and program underwater robotic vehicles, they are learning engineering fundamentals which span virtually every engineering discipline. Additionally, students are motivated by an exciting and stimulating design scenario.

The underwater environment presents unique design challenges and opportunities which would not be encountered in, for example, a wheeled land vehicle project. The motion of an underwater vehicle is more complex (six degrees of freedom) as compared with the three degrees of freedom of motion on a planar surface. Additional engineering issues include propulsion, drag, buoyancy and stability. Practical construction problems include how to waterproof electrical components. The challenge of creating a robot which can be sent to explore a hostile and inaccessible environment is also motivating and stimulating to many students.

Why use LEGO?
LEGO is particularly useful for discovery based learning due to its ease and speed of assembly (see, for example, Portsmore et al., 2004, and Wang et al., 2004). This speed reduces the time between conception of an idea and its implementation, enabling students to discover through trial and error, rapidly test a range of alternative designs and evolve their designs iteratively by observing the relationship between structure and function. In contrast, when students use conventional materials, the construction process is lengthy and frustrating. Time constraints prevent students from evolving their designs through multiple iterations of testing and modification.

Marine engineering at Stevens
Stevens Institute of Technology has a distinguished history of pioneering innovation in the fields of marine engineering and naval architecture. John Stevens designed the first American-built steam locomotive in 1825 and was a pioneer in the development of the steamboat. The Stevens family was active in the design and construction of ironclad vessels for the U.S. Navy and assisted in building "America", the winner of the first America’s Cup yacht race in 1851.

Founded in 1935, the Davidson Laboratory (Center for Maritime Systems) remains one of the world's leading centers for research and education in the areas of Naval Architecture, Ocean Engineering, and Marine Environmental Engineering. The Davidson Laboratory research facilities include a 313ft towing tank of 6ft depth and a 75ft square oblique sea basin tank of 5ft depth.

Having traditionally been at the forefront of novel marine technologies, it is a natural progression for Stevens to incorporate underwater robotic vehicles into the engineering curriculum. Stevens is an ideal setting in which to develop these new discovery based educational materials, due to its unique marine engineering facilities and wealth of expertise.

Education at Stevens
Center for Innovation in Engineering and Science Education (CIESE) is nationally recognized for its unique and compelling Internet-based curriculum materials for K-12 science, technology, engineering and mathematics (STEM) education. In 2004, CIESE became part of the Charles V. Schaefer School of Engineering at Stevens Institute of Technology and expanded its mission to catalyze and promote innovation and use of best practice in undergraduate engineering education at Stevens.

Discovery based learning

Discovery learning (Bruner, 1966) is a cognitive instructional model in which students are encouraged to learn through active involvement with concepts and principles, and teachers encourage students to have experiences and conduct experiments that permit them to discover principles for themselves.

Although discovery learning is frequently employed in an early childhood development setting, the instructional model offers several advantages to a high school or undergraduate setting. It arouses students' curiosity, motivating them to continue to work until they find answers (Berlyne, 1965). Students also learn independent problem solving and critical thinking skills because they must independently analyze and manipulate information.

Students often benefit more from being able to engage in active learning by "seeing" and "doing" things than from passive learning by listening to lectures. Tackling material from several perspectives and persevering with unresolved problems improves students' core intellectual skills-they learn how to learn independently. Cognitive development is not the accumulation of isolated pieces of information; rather, it is the construction by students of a framework for understanding their environment. Teachers should serve as role models by solving problems with students, explaining the problem solving process and talking about the relationships between actions and outcomes. Observing students during their activities, examining their solutions and listening carefully to their questions can reveal much about their interests, modes of thought and understanding or misunderstanding of concepts (Slavin, 1994).

Discovery based learning is a particularly effective means of teaching the iterative approach to engineering design. Students are encouraged to approach engineering problems through an iterative sequence of steps: Design/Test/Modify (figure 1). In contrast, surprisingly little of conventional engineering curricula is devoted to this design process, with the learning experience of engineering students often bearing little resemblance to the activities of professional engineers in industry.

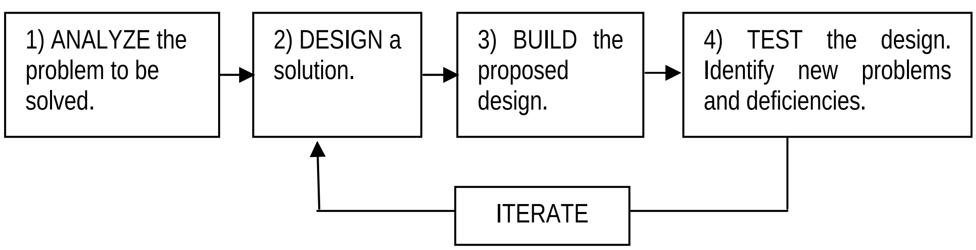

Figure 1: The iterative design process

The Stevens underwater robotics student project program

Educators and engineers at Stevens Institute of Technology are currently engaged in developing a set of educational modules, which will teach fundamental engineering principles through the design, construction and testing of underwater robotic vehicles. The strategies incorporated into our underwater robotics projects foster an active, discovery learning environment that integrates many mathematical, scientific and engineering principles and will support conceptual and skill-based learning, application of principles to novel situations, collaborative learning and cooperative group skills.

It is intended to incorporate these modules into the Stevens Institute of Technology core freshman curriculum, but the modules will be designed so that they can be easily and flexibly incorporated into existing curricula at many other colleges and universities. An adapted module will be created and disseminated for use in high schools.

It is also proposed to assess the effectiveness of these modules for teaching fundamental engineering skills in accordance with established educational theory. A trial group of students will experience a pilot implementation of the modules, while a control group of students will not. The subsequent performance of both groups will be studied and compared.

Students will assemble LEGO structural elements, motors, gearing, sensors and other materials into underwater robotic vehicles that can be programmed and controlled through small battery-powered microcomputers called RCXs, using ROBOLAB – a visual programming language based on LabVIEW. Students will be able to add a variety of sensors to their vehicles, eventually programming the machines to perform simple autonomous tasks, responding to sensor stimuli with intelligent motion.

Students will begin with a mechanical design project, creating stable vessels which will support the weight of motors, controllers and batteries at near to neutral buoyancy. They will investigate underwater propulsion, running a series of experiments to optimize thrust based on gearing and propeller design. They will also investigate ways of controlling vertical motion in the water. They will build controllers for the LEGO motors and will evolve their designs into ROVs, underwater vehicles controlled remotely by a human operator via connecting wires.

The students will next learn how to program the RCX controller using ROBOLAB. Students will be able to add a variety of sensors to their vehicle, and program the RCX to interpret and respond to sensory data. The ultimate design challenge will be to develop a vehicle which will perform simple, unaided, autonomous tasks. Students will test their designs by entering their robots in a competition to complete an assortment of challenges.

Students will be encouraged to extend their project work to include other kinds of control systems and programming languages.

Building remotely operated underwater vehicles – a pilot project implementation

Background

Exploring Career Options in Engineering and Science (ECOES) is a residential summer program at Stevens Institute of Technology, designed for students approaching their senior year of high school. ECOES enables students to learn about a variety of engineering and scientific study options and careers and interact with professional engineers and scientists. A major component of the program is a 12 hour engineering design project. During the 2005 summer program, 30 ECOES students participated in building remotely operated underwater vehicles as their engineering design project.

Materials

Students were provided with a selection of LEGO including several motors (with and without gear reduction), battery boxes and leads, gearing, structural and mechanical components. Also provided, were a selection of plastic propellers (obtainable from hobby stores) mounted on LEGO axles (figure 2). Additional materials included Styrofoam, modeling clay, a selection of weights (nuts and bolts work well), rubber bands, string and duct tape. A 30 inch deep inflatable pool was used to test the designs. Wiffle balls were specified as the objects to be retrieved and manipulated by the ROVs.

Figure 2. Propellers

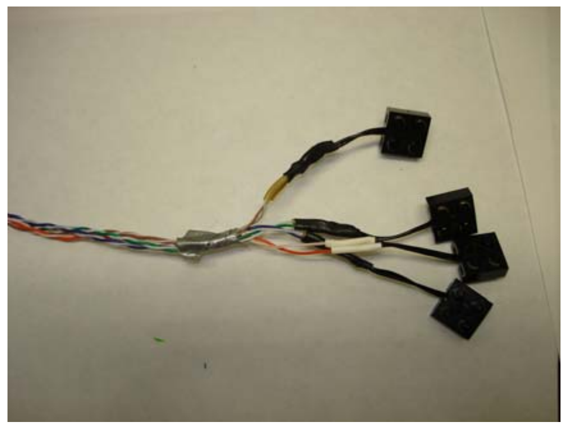

Figure 3. Control cable with LEGO compatible connectors

Students were issued with a variety of electrical components, with which to create a control system and had the opportunity to learn soldering and simple circuit design and debugging. Long control cables were pre-assembled for the students. These cables contained eight wires (enough to control four independent motors) and were terminated with four LEGO compatible end connectors (figure 3). To build a control system, several three position double throw switches were supplied. Each switch can control a single motor with three possible states, Forward/Off/Reverse. Pre-drilled aluminum boxes were supplied for mounting the switches. Additional supplies included 9-volt batteries, battery connectors, wire, solder, electrical tape, shrink wrap, soldering irons, solder suckers, wire snips and strippers and safety glasses. A digital multimeter was useful for debugging circuits.

It was noted that two different LEGO motors are commonly available, the “9 volt motor” and the “9 volt motor with gear reduction”. The “9 volt motor” runs much faster than the geared motor, but also appears to be considerably more powerful overall. The students were initially issued only the gear reduction motor, as this forced them to design relatively complex gearing systems to generate sufficient propeller speed.

Procedure

Students were divided into five person teams. The project consisted of five laboratory sessions, amounting to twelve contact hours, over a two week period. In each session the student teams were given progressively more complex, intermediary design challenges. Intermediary challenges initially involved developing simple motorized surface vessels, progressing to fully controllable, submersible vehicles and motorized grabbers. As a final challenge, each team had to use their ROV to retrieve and manipulate objects on the bottom of a pool of water.

The intermediary design challenges included:

1) Design a surface vessel with a single motor and various propeller options, optimizing gearing ratios to maximize straight line speed.

2) Design a surface vessel with controlled steering, using two independently controlled motors. The challenge involved negotiating a figure 8 course, around two buoys, in the least amount of time.

3) Develop an electrical control system for four independent motors.

4) Add a third motor to the vehicle, enabling vertical motion in the water column.

5) Design a motorized mechanical manipulator which can grasp specified objects.

6) Combine the products of stages 3, 4 and 5 to produce a vehicle which can retrieve the greatest number of objects from the bottom of the pool within a five minute period. Retrieved objects must be deposited in bins at various depths in the water in order to score points.

Many of these challenges have a variety of solutions. For example, challenge 2 can be solved using twin propellers, a single propeller plus rudder or a single propeller with variable direction.

At some stages during the project, specific roles were assigned to each team member including:

- Propulsion engineers
- Electrical control system engineers
- Grabber designers

Students were encouraged to rotate through different roles in order to maximize the breadth of their experience. The allocation of different roles was also intended to maximize student participation, by preventing too many students trying to work on the same part of their design at any one time.

In each laboratory session, instructors delivered short, interactive lectures or “Tech-Talks”. These were limited to around 10 minutes each. On occasions where two Tech-Talks were delivered in the same session, they were separated by periods of practical work. Tech-Talks were designed to convey the underlying scientific and engineering principles which were necessary to complete each successive stage of the design challenge. Tech-Talk subjects included:

1) Gearing mechanisms, torque, speed and thrust.
2) Different ways to achieve two degrees of freedom of motion.
3) Electrical circuits and control panel design.
4) Buoyancy, Archimedes principle and how to move up and down.
5) Grabbers, graspers and manipulators

Students received handouts containing supplementary information including:

- Photographs and descriptions of industrial and research ROVs and AUVs.
- Notes on important aspects of submarine design.
- Notes on circuits and electrical design issues.

Results

All student teams succeeded in creating remotely operated underwater vehicles which successfully completed the final design challenge. Several important and encouraging features of the student's work were observed:

- Every student team arrived at original and creative solutions to the design problems. Each team's solutions were significantly distinct from those of other teams.
- The iterative engineering design process was highly apparent in each team's work, with solutions evolving through successive cycles of designing, testing and modification.
- Design solutions were achieved through invention, experimentation and discovery and not through didactic, prescribed instructions.
- The structure of the course and the nature of the design challenges successfully induced positive teamwork habits to be developed within each team.
- Students were highly engaged in the work, enjoyed what they were doing and wanted to do more.
- Students took pride in what they created and in their ability to solve significant engineering problems.

The figures on the following page illustrate the evolution of the student designs over the course of the five laboratory project sessions. Additional pictures, information and the student team's final presentations can be viewed on the project web site: http://www.k12science.org/ecoes2005/ecoes1.html

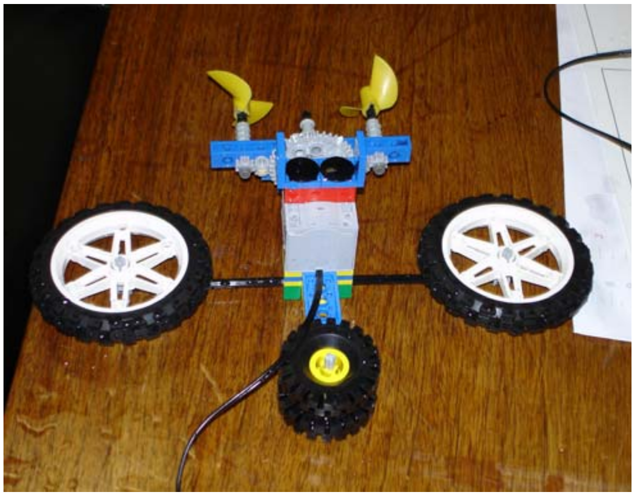

Figure 4. A design solution to challenge 1.

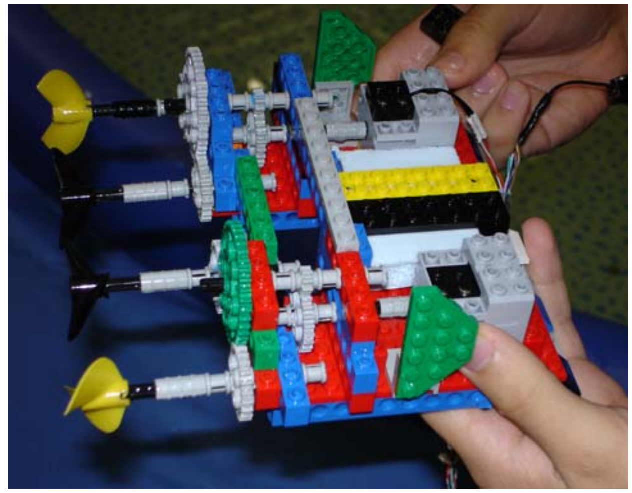

Figure 5. Steering with two motors.

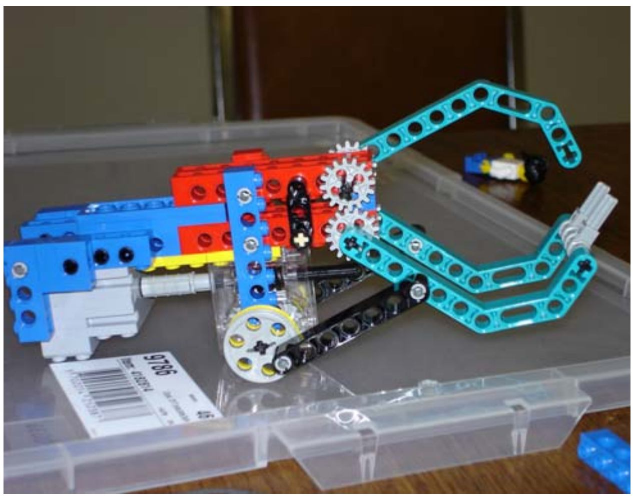

Figure 5. A grabber design.

Figure 6. An electrical control system.

Figure 7. Final designs. Submersible vehicles with grabbers.

Future work- from ROVs to AUVs

The original intention of this work was to enable students to develop fully autonomous robot vehicles, which could respond to sensor stimuli with intelligent motion. The pilot implementation reported above goes partway toward achieving this goal.

So far, student projects have involved creating wire guided ROVs, controlled by a human operator. To develop truly autonomous behavior, the underwater vehicles will need to be equipped with sensors and a programmable controller. The LEGO RCX controller, LEGO sensors and ROBOLAB programming language may provide a suitable basis for creating this additional functionality.

We envisage a project split into two parts. The first part will center on the mechanical challenges of creating a stable wire guided ROV capable of bearing a payload equal to the weight of an RCX controller and batteries. A second part of the project will see the human controlled ROVs evolving into self-guided AUVs. Sensors and a waterproofed RCX will be added to the vehicles, and the RCX will be programmed to produce simple autonomous behaviors.

Alternative controllers and programming languages will also be considered. The RCX controller and ROBOLAB language may prove to be valuable stepping stones towards more complex languages and control systems, especially for students with little prior experience of computers and programming.

Summary

Educators and engineers at Stevens Institute of Technology are collaborating to create discovery based educational materials, teaching a wide range of engineering skills and scientific principles through student projects involving underwater robotics.

In a successful pilot implementation, 30 high school students succeeded in creating remotely operated underwater vehicles, electrical control systems and motorized grabbers.

It is intended to add a second stage to the project work in which sensors and programmable controllers will be used to develop autonomous robotic capabilities in the vehicles.

The discovery based learning approach to science and engineering education has proven effective, engaging and stimulating. It is particularly compatible with student projects which emphasize the iterative engineering design process. LEGO components have substantially facilitated the design process by reducing the time between conception of an idea and its implementation.

Acknowledgements

The authors gratefully acknowledge the support of Keith Sheppard, Associate Dean of the Charles V. Schaefer, Jr. School of Engineering at Stevens Institute of Technology.

Thanks are also due to Tim Diehl for his assistance and to Chris Rogers, Merredith Portsmore, Amos Winter, Theo Brower and Morgan Hynes for their LEGO-ology and inspirational designs.

We dedicate this paper to the students of the 2005 ECOES program.

Bibliographic Information

Berlyne, D.E., Curiosity and education. In J.D. Krumboltz (ed.), Learning and the educational process. Rand McNally. 1965.
Bruner, J., Toward a Theory of Instruction. Harvard University Press. 1966.
Portsmore, M.D. and Rogers, C., Bringing Engineering to Elementary School. Journal of STEM Education. Vol 5. 2004.
Slavin, R., Educational Psychology: Theory and Practice. Allyn and Bacon. 1994.
Wang. E., LaCombe, J., and Rogers, C., Using LEGO Bricks to Conduct Engineering Experiments. Proceedings of the ASEE Annual Conference and Exposition. 2004.

Biographical Information

RUSTAM STOLKIN (rstolkin@stevens.edu)
Rustam Stolkin is a Research Assistant Professor at the Center for Maritime Systems, Stevens Institute of Technology. He received a MEng degree in Engineering from Oxford University and a PhD in Robot Vision from London University. His research interests include robotics, computer vision, machine intelligence and sensor systems.

LIESL HOTALING (lhotalin@stevens.edu)
Liesl Hotaling is Assistant Director of the Center for Innovation in Engineering and Science Education (CIESE), Stevens Institute of Technology. She received a B.S. in Marine Science from Fairleigh Dickinson University, a M.A.T. in Science Teaching from Monmouth University and a M.S. in Maritime Systems from Stevens.

RICHARD SHERYLL (cyclopsrd@aol.com)
Richard Sheryll is a Research Associate and Ph. D. candidate in Ocean Engineering at Stevens Institute of Technology. He received a B.S. in Oceanography and an A.S. in Electrical Engineering from State University of New York. He is an experienced design engineer specializing in the development of deep-ocean sampling systems.