Discovery based learning in the engineering classroom using underwater robotics

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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.

1 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 other simple 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.

1.1 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 use of projects based on small robotic vehicles is now widespread in engineering curricula, however these are predominantly wheeled, terrestrial vehicles. Such projects often reduce to little more than exercises in applied programming, losing the opportunity to present substantial mechanical challenges or to incorporate real interdisciplinary engineering design. In contrast, the
underwater environment presents unique design challenges and opportunities. The motion of an underwater vehicle, through a three dimensional space, is more complex. 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.

1.2 Why use LEGO?
Our students work with a combination of LEGO and additional materials, which are particularly useful for discovery based learning due to their ease and speed of assembly (Portsmore et al., 2004)¹, (Wang et al., 2004)². 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. Often there is no time allotted for the students to fail, analyze the failure and then modify their design. In contrast “We know that students will learn most deeply and profoundly when they……have an opportunity to try, fail and receive feedback on their work” (Bain, 2005)³.

1.3 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.

1.4 Education at Stevens
The 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.
2 Discovery based learning

Discovery learning (Bruner, 1966)\(^4\) 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)\(^5\). 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)\(^6\).

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](image)

3 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.

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.

Future work will involve students adding a variety of sensors and small microcomputers to their vehicles, eventually programming the machines to respond to sensor stimuli with intelligent motion. 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.

We are investigating the use of various different kinds of control systems and programming languages. Students may benefit from starting with simple control systems and accessible graphical programming languages before progressing to more sophisticated controllers and advanced syntactical languages.

4 Building remotely operated underwater vehicles – a pilot project implementation

4.1 Background
We have successfully implemented pilot student projects, building wire guided ROVs. These projects have included summer projects with teams of senior high school students consisting of 12 contact hours over five sessions. We are currently piloting the project with freshman undergraduate projects consisting of four contact sessions of ninety minutes with additional periods of unsupervised laboratory time.

4.2 Materials
Students were provided with a selection of LEGO including several motors, 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.
Students were issued 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 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.

4.3 Procedure
Students were divided into five person teams. The project typically requires four to five sessions with instructors plus additional time for students to work on their projects. In each session the student teams are given progressively more complex, intermediary design challenges. Intermediary challenges initially involve developing simple motorized surface vessels, progressing to fully controllable, submersible vehicles and motorized grabbers. As a final challenge, each team has to use their ROV to retrieve and manipulate objects on the bottom of a pool of water.

The intermediary design challenges include:
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 are assigned to each team member including:
- Propulsion engineers
- Electrical control system engineers
- Grabber designers

Students are encouraged to rotate through different roles in order to maximize the breadth of their experience. The allocation of different roles is 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 deliver short, interactive talks. These are limited to around 10 minutes each. On occasions where two talks were delivered in the same session, they are separated by periods of practical work. These short talks are designed to convey the underlying scientific and engineering principles which are necessary to complete each successive stage of the design challenge. Additionally, these talks are designed to show students how the theory that they are studying in mathematics and physics classes relates in tangible ways to the real, practical engineering problems which they are tackling. Talk subjects include:

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 receive 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.

4.4 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. Straight line motion with single motor.  
Figure 5. Steering with two motors.  
Figure 5. A grabber design.  
Figure 6. An electrical control system.
5 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.

Ongoing work is investigating appropriate choices of autonomous robotics challenges. These need to be intellectually substantial, meaningful enough to engage students, yet realistically achievable by freshman students in a short space of time using relatively simple components.

Various choices of controllers, programming languages and sensors are being considered. Students with little prior experience of computers and programming may benefit from a gentle introduction to simple controllers and graphical programming systems, before progressing to more sophisticated controllers and syntactical programming languages.

6 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, 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.

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Bibliographic Information


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