Chapter 18

Using Underwater Remotely Operated Vehicles as an Engineering Education Tool

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Starting in 2004, the Department of Mechanical Engineering at Rowan University introduced a new tool into its program: Remotely Operated Vehicles (ROVs). The tool is used at different aspects of education. As a coursework project, graduating ME seniors researched, designed, built, competed and reported with underwater ROVs to assess their design skills before heading out to start their careers. It tests a wide range of engineering background in one single project and gauges the soft skills such as teamwork, self-learning, communication and evaluation. As a student research project, a multidisciplinary student team developed a robotic field ROV to help biological scientists automatically sample or observe a water body. This project helped to attract talented students to further their education in graduate study. Meanwhile, the ROV also serves as an outreach tool to local high school students and the public.

INTRODUCTION

Reform of engineering education is sweeping the world amid rapid advances in technology and changes in the world economy. At Rowan Engineering, engineering education is also under constant review to prevent "teaching more about less" [1]. New initiatives are introduced, new ideas are circulated, and new practices are adapted. In 2004, we started a new practice of using Remotely Operated Vehicles (ROVs) as an engineering education tool.

First, let us review current industry trends and offer the following observations that are fundamentally influencing our decision making. In general, engineers can be roughly divided into three major groups (Figure 1): A) Scientists and researchers; B) Research & Development (R&D) engineers; C) Industrial/field engineers.

People in Group A are those working in research labs of research universities, government agencies and a few fundamental industrial research labs. They usually have a PhD degree and produce most of the scientific, theoretical breakthroughs. The engineers in Group B are working in the R&D centers of major corporations. They often have at least a master's degree or have many years of experience in one dedicated field. Most of them have close working relationships to the people in Group A and have access to state-of-art equipment. These people are the major source of industrial innovations and are the developers of many core technologies. Group C is the largest and comprises practicing engineers. They often decide to leave school with a Bachelor's degree. Some of them might come back to school when they move to managing role or a new field. Their roles often are to integrate or maintain a system to suit customers' needs, or design and manufacture a product using existing technologies.

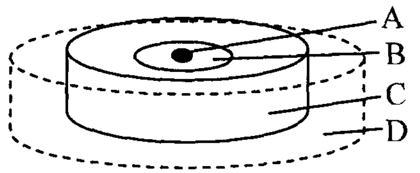


FIGURE 1
GENERAL ENGINEERING POPULATION

Since we are involved with a non-doctoral engineering program, we believe most of our students will be in Group C with a small number of them in Group B. In our ten-year history, a few students have entered Group A by attending to doctoral program of research universities. In general, students in Groups A and B are self-motivated. They often get better attention from faculty members due to their better academic performance with similar goal to the faculty members themselves. However, Group C is by far the largest group in both school and industry. We need to find ways to optimize our education on the students in Group C without compromising the promise of students in Groups A and B.

Meanwhile, there is also an often-neglected population of 'engineers' – the general public (Part D in Figure 1). Despite the fact that they are not directly involved in engineering, the field of engineering education needs their support, engineering projects need their approval, and most importantly, they are the ultimate customers of all engineering work.

Based on the above observations, we started to look for tools or methods to help us transform traditional engineering education. Additionally, we observed that use of robotic equipment is quickly gaining momentum. Robotics is used to enhance productivity, explore the unknown [2], enable scientific discovery [3], and entertain the public [4]. According to the prediction of Bill Gates, founder of Microsoft, robotics will be the next wave of technological revolution after the personal computer and Internet [5]. Many schools, including Rowan University, have already started to take advantage of the interest in robotics to enhance the learning experience [6].

Among the different kinds of robotic systems, Remotely Operated Vehicles (ROVs), especially the underwater ROVs are of particular interest to us. Though not an everyday appliance, they play a critical role in various important fields, such as marine science [7], oil/gas exploration [8], telecommunications, military, and environmental protection. For deep-water operation, "working class" ROVs are used to resist extreme, harsh environment and carry heavy duty rigs. In contrast, observant class ROVs are small scale and are for light duty. In recent years, research activities using ROVs are picking up in

many institutes [9], many ROV competitions [10] are hosted worldwide, and some schools [11] have used ROVs in their educational activities.

In the Department of Mechanical Engineering (ME) of Rowan University, we adapted the idea of integrating underwater ROVs into our curriculum. Meanwhile, instead of keeping it as a side project among a few students, we employed it at every aspect of education: regular teaching, student research and outreach. It targets the audience throughout group B, C and D mentioned above.

In teaching, the underwater ROV serves as nearly a final assessment for the faculty to determine the students' state of readiness to do design, not just to integrate their four years of study as in a capstone design course. That is, the students are not simply synthesizing the knowledge they have gained through the curriculum, which they have been doing continuously through our curriculum, but they are demonstrating their level of expertise in design after several years of practice. This is especially important for those who will join the workforce immediately after graduation. Before they graduate, the students need to design and build an amateur-grade underwater ROV with mostly off-the-shelf parts and material [12]. The procedure is a formal design-build-test-report-evaluate process, which closely mimics their future working environment.

In contrast, a similar but more challenging ROV project was developed in Rowan Engineering for research purposes. It serves as a stepping-stone for the students who want to further their education and pursue a career in research and development. A multidisciplinary team is currently developing a series of robotic field ROVs called the Interactive Mobile Aqua Probe & Surveillance (IMAPS) system [13]. The robots are used by biological science faculty and students for their research and educational purposes.

Besides the regular education and research applications, ROVs also inspired activities outside the classroom. As we will describe in detail later, a project involving the building of an ROV has been successfully used as an outreach tool to demonstrate engineering to high school students [14]. These students may or may not select engineering as their career; however, their exposure to ROVs and engineering in their early life will help them to understand the importance of the subject.

EMERGING TOPICS: UNDERWATER ROV

In Rowan Engineering, there is an eight-semester course series called the Engineering Clinics [15]. These are purely project-based courses and are the a superset of capstone projects in traditional engineering programs. The clinics provide a systematic training of students on design, analysis, fabrication, communication and teamwork. In the Junior and Senior year, the projects in Engineering Clinics are often based on faculty research or external industrial projects. This unique setting makes the projects naturally distinct from each other. However, we need a complimentary course to put all students on a common ground and gauge the result of the four-year long training on clinics before graduation. Emerging Topics – Building a Remotely Operated Vehicle, is such a course that addresses this need and provides a touchstone test to graduating seniors. The capstone-like project was inspired by the competitions hosted by Marine Advanced Technology Education (MATE) [16] from Monteray Peninsular College and modified to suit the format, scope and goal of our program.

Since it is the seniors' last major project in college, the course will focus on applying existing expertise instead of training new skills. The students should have strong teamworkship skills and be able to work under pressure of competition and deadlines.

Wk	Tuesday	Thursday	Assignments
1	Introduction	History and Fundamentals	Read book, study background, paper design
2	Structure	Buoyancy and ballast	
3	Design issues	Material	
4	Sealing	History paper & presentation	
5	Motor & Propeller	Build and test a propeller	Pick and present one technology, read book, fabricate parts
6	Power	Design & Build ROV	
7	Control	Design & Build ROV	
8	Payload & Tool	Design & Build ROV	
9	Spring Break	Spring Break	
10	ROV technology presentation, paper due		
11	Fluid dynamics	Design & Build ROV	Assemble, test, practice and improve
12	Intro. to AUV	Design & Build ROV	
13	Practice and test	Practice and test	
14	ROV Competition (combined for half day class)		
15	Project presentation		Summarize and reflect
16	Finals' Week	Final design report due	

TABLE 1
SAMPLE CLASS SCHEDULE

They should be able to learn any unspecified but necessary course material, and communicate effectively with oral and written, and in multimedia formats. The faculty will just facilitate the project. The students need to manage the projects and personnel themselves and participate in the evaluation process. In short, the goal of the course is to warm the seniors up and prepare them for a smooth transition to industrial jobs or graduate study, especially the former. Table is a sample class schedule.

Like most real industrial projects, there is no official textbook but a multitude of supplementary materials from various sources. A book by Bohm et al. [17] gives introductory knowledge. Meanwhile, extensive use of library and Internet research provides in-depth information. Generally, we divide the semester into three phases that concern: Background Study; Technology Research; and Design, Build and Compete.

In the background study, the students dive directly into the world of underwater ROVs, AUVs (Autonomous Underwater Vehicles) and other modern marine technologies. Since most students are not familiar with marine science and technology, it is a great opportunity to test-drive their self-learning capability.

In the technology research phase, the instructor covers several marine technologies using seminar format. Meanwhile, each student group is required to choose one specific technology and study it in detail. Example topics include: underwater communication, deep sea localization, and high speed propulsion. At the end of this phase, each group is required to submit a report written in the ASME (American Society of Mechanical Engineering)

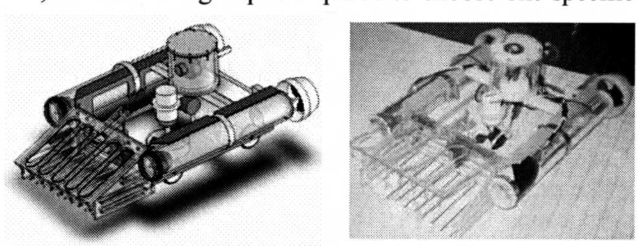


FIGURE 2
(LEFT) CAD RENDERING OF AN ROV. (RIGHT) THE ROV BUILT FOLLOWING THE DESIGN WAS PUT INTO ACTION

format. They need to give a convincing recommendation with pros and cons assuming the particular technology will be used in a real-life commercial ROV design. They also need to disseminate the newly acquired knowledge to the entire class by giving presentations.

In the design and build phase, the students need to combine the knowledge they learned in their past years and the information obtained in this course to design and fabricate. For example, students learned SolidWorks, a solid body CAD software, in their sophomore year. In this project, they need to use this software to demonstrate their design before fabrication. In Figure 2, a CAD rendering and a fabricated ROV are compared side by side. The students are also required to perform calculations to determine the center of gravity, center of buoyancy, and stability as well as predict such performance measures as maximum speed, thrust, etc.

Besides demonstrating their engineering skills, the students also need to practice their project management skills. To simulate the formal approach in industry, they need to plan the progress with a Gantt chart and follow up with a weekly progress report. Except for the provided materials such as PVC pipes, camera and electric wire, they need to keep a record of every single component they use. The total budget for non-standard components should not exceed $20 and will be scrutinized in the final presentation.

The last and most eagerly anticipated part of the third phase is the final contest, when tricks are revealed and the designs are challenged. Currently, the ROV contest includes four events:

<u>Underwater maze.</u> ROVs need to swim across a covered 3m×1.2m×1.2m maze laid on the bottom of the swimming pool.

<u>PVC mining.</u> ROVs need to pick up various objects (e.g. PVC pipe fittings) from a 1.2m×1.2m mining zone, and then dump them onto a 1m×1m dumping area 3m away.

<u>Sprint relay.</u> ROVs swim from end to end between two marks 7 meters apart.

<u>Tug of war.</u> Two connected ROVs drag each other toward its side of the pool.

The final grade reflects the combined effort of research, paper writing and presentation, as well as competition results and peer evaluations. Each presentation is graded by the entire class on technical soundness, presentation skills, and handling of questions. Each paper is reviewed by both instructor and students following a common peer review procedure. At the end of the semester, all team members evaluate each other by filling out a peer evaluation form. Through these activities, the students learn and practice the skills of evaluation and critical thinking in addition to collaboration and teamwork. Meanwhile, by emphasizing different aspects of the project at different stages, students with different learning styles and personalities can always find their favorite spots and take the lead in turn. For example, the visual and auditory learners like the seminar and enjoy the multimedia presentations by both instructor and their peers. They also spend a great deal of time and energy to research the topics they have chosen. Meanwhile, the kinesthetic students are quick to design and build their components at every available moment during lab time. They also tend to be the driving force to push the team toward winning the competition.

MULTIDISCIPLINARY STUDENT RESEARCH WITH ROV

According to our observation, about a quarter to a third of Rowan seniors will opt to further their education after graduation. Using the research on a special hybrid field ROV as a platform, we have successfully prepared many talented students for their graduate

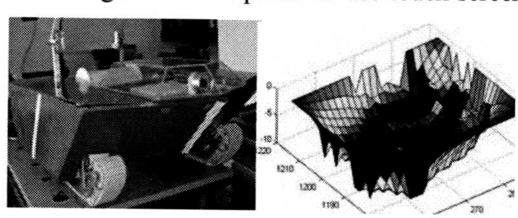
study. The project is to design and build a robotic aquatic sensor called the Interactive Mobile Aqua Probe and Surveillance (IMAPS) system [13]. It is a multidisciplinary project among Mechanical Engineering (ME), Electrical and Computer Engineering (ECE), and Biological Science (BIO). The goal of the project is to use a robot to scan and test a water body such as a lake, a river, a fishing farm or an estuarine area.

For biological science research and environmental protection, field sampling and data collection are fundamental tasks. Traditional manual method is both labor intensive and time consuming. The method also depends heavily on weather conditions. Meanwhile, existing research level ROVs, AUVs and research vehicles are not suitable for shallow water and complex terrain. Most of them are also not affordable for small research programs. Therefore, Rowan University decided to develop an easy to use and inexpensive light-duty research ROV for low to medium budget research groups.

The robotic ROV takes advantage of the same technologies on material, sealing, motor control and buoyancy analysis as the ROVs in Emerging Topics. However, as a research project, many advanced sensors and capabilities are introduced. For example, an on-board Windows XP-based computer receives task descriptions and autopilot itself to perform the tasks, in addition to following individual manual steering commands. A wireless Ethernet bridge enables communication without direct eye contact 1.5 mile away. A multi-sensor package can be sent to a depth of 30 to 50 meters, which is enough for most fresh water applications. Meanwhile, a graphical user interface (GUI) with built-in autonomous navigation algorithms greatly improved user experience compared to mechanical control boxes.

The IMAPS robotic field ROV has evolved through three major incarnations after development over four semesters (Figure 3A). It changed from a pure tele-operated observation platform to an amphibious intelligent robot. It also has been tested and applied by biological science faculty and students in their research and education activities. For example, it can quickly scan a water body and generate a 3D map of depth, PH level or other biological or chemical parameters for further analysis (Figure 3B).

By participating in this multi-disciplinary research project, many students realized for the first time how critical their work is and how much it is appreciated by people in other majors. They also polished their communication skills with people from different backgrounds. With biological people as their clients, they have to give up technical jargons and explain in plain English. This in turn helps them grasp the knowledge at a higher level. They also learned to understand the needs and requirements of their customers. For example, although engineering students considered short-cut keys as easy and simple to use, they finally realized that biologists in field prefer to use touch screen with graphical interaction. At the same time, engineering students also expanded their horizon of knowledge. For example, almost everyone in the team could quickly name the common pollutants in local ponds, as well as giving a quick local eco-tour. By glancing at the numbers retrieved from the biological sensor, they could almost immediately tell whether or not the water is clean and safe.



(A) (B)

FIGURE 3

(A) THE THIRD GENERATION AMPHIBIOUS IMAPS. (B) DEPTH PROFILE OF A LOCAL POND OBTAINED BY IMAPS

Due to its emphasis on research, the IMAPS project has become a cradle for nurturing future researchers. The students presented their work at several local and national conferences. It was a great experience for the undergraduate students to prepare their papers and make presentations, and network with their peers. Within two years, the project trained more than a dozen students. Among the six who have graduated so far, two have gone on PhD programs at research universities and two have been admitted to Master's programs. We expect that more students will select to go to graduate school after participating in the IMAPS project.

ROV AS AN OUTREACH TOOL

Like many other engineering schools, Rowan Engineering also faces the challenge of attracting more diverse talents, especially female and underrepresented minority students. To many students in this population, engineering is often considered out of their financial and academic reach. Even for the general public, engineering is often stereotyped as boring and difficult. We believe it is the duty of engineering schools to educate the public and demystify engineering.

Starting in 2004, Rowan Engineering has joined forces with another university-sponsored program called CHAMP (Creating Higher Aspirations and Motivations Project)/GEARUP (Gaining Early Awareness and Readiness for Undergraduate Programs) [14]. CHAMP/GEARUP is a state program serving 7th through 12th grade students in the public schools of the New Jersey cities of Camden, Millville, Vineland and Bridgeton. These are economically disadvantaged areas with low college enrollment rates. In general, the goal of the CHAMP program is to provide various enrichment activities such as mentoring, tutoring and counseling to improve the students' academic performance and prepare them for college. They also organize a summer camp to enable junior and senior high school students to stay and study at Rowan University for six weeks, so they can personally experience college life. The Department of Mechanical Engineering uses underwater ROVs to enrich the program and to provide an opportunity for the students to preview the engineering curriculum.

Typically, in the underwater ROV workshop, the students are offered preassembled controllers and propellers. Several engineering faculty members and student assistants are stationed with them to help them brainstorm the design, cut the PVC pipes, troubleshoot problems, and test prototypes. Students operate their ROVs and compete independently. The workshop has proven to be a success. The feedback from the students has been overwhelmingly favorable. Among all the activities in the program, including dance, music and literature, the engineering component has been the most popular. With the hand-in-hand help, the students became comfortable to put their hands on parts and tools. They are also extremely proud of what they have achieved after a week's hardwork (Figure 4). It is unrealistic to expect to change entirely the stereotypical mindset of many high school students with a six-week workshop. However, when the students go back to their high schools, they spread positive words about engineering. The program has become ever more popular each year. It will, hopefully, eventually translate into higher enrollments of underrepresented students.

FIGURE 4
TWO HAPPY CHAMPERS SHOW OFF THEIR ROV

ROV ADVANTAGES

Many different ROV-like tools have been introduced in different institutes to keep the students' hands dirty and keep their interest focused, such as R/C cars, mini robots (such as Lego Mindstorm [18], Parallax BOEBot [19]), and aerial vehicles (such as a blimp or a helicopter [20]). Compared to these tools, underwater ROV holds its position with some unique benefits toward engineering education:

1. It requires designing and building something that most of the students have not seen before. It gives students a chance to test their ability in system integration and self-learning besides practicing the teamwork and management skills.
2. It is more challenging than land-based ROVs. An underwater ROV needs to travel in three independent directions, i.e., forward/backward, left/right, and up/down. To keep it neutrally buoyant is also not an easy task, especially when there is a change of payload after picking up underwater objects. Further, keeping the electric components dry in water with inexpensive materials is naturally difficult. Indeed, many cameras were flooded in practice runs or in the final contest.
3. It is more controllable than an airborne vehicle since the speed of a submarine is relatively low, buoyancy is easier to manage than aerodynamic lift, and the operating zone (testing water tank or a swimming pool) is readily defined. While outdoor flight tests are often subject to weather conditions, the indoor environment is relatively easily controllable. Hence test-drives are easier to manage for underwater ROVs.
4. It is scalable for large or small projects. The different functions of a ROV can be decoupled and different levels of assemblies can be provided. For example, we can require senior undergraduate students to build a full-version ROV from scratch and lead student team to build robotic ROV. On the other hand, if we supply pre-cut parts, pre-assembled thrusters, and remote controllers, a stripped-down version will be suitable for high school students in a multi-week long schedule.
5. It is perceived to be more rewarding to students owing to the fact that it is generally a mysterious world underwater, even just a meter deep. After all, we cannot see clearly through turbid water but can easily send our eyesight high.

Over all, in a world full of distractions, the educators are constantly competing for the attention of the students. The ROV project is designed to pull the students gently back and engage them in learning, which is fundamental to realizing all the objectives of education. This can be clearly illustrated by the integration of electronics into the project. Industry is hungry for people with electro-mechanical skills. Nevertheless, to many "pure" Mechanical Engineering students, any electrical component, even a piece of wire, is considered a mystery in an unknown territory. Although all students are required to take courses like Networks and Electronics, many manage to reset themselves quickly. One strategy at Rowan is to repeat and retain. We have developed or modified several courses using this strategy, such as the introduction of a new course called Mechatronics, and the implementation of many hands-on projects with electrical or multidisciplinary components [21, 22]. Among these practices, designing and building ROVs is one that has proved to be successful to engage the entire class.

Discussion and Summary

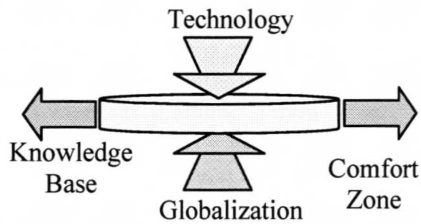


FIGURE 5
STATUS OF FUTURE ENGINEERS

The engineering workforce all over the world is squeezed by two trends (Figure 5). One is globalization. Modern communication and transportation infrastructures bring competition from millions of engineers worldwide to our very doorstep [23, 1]. The other is advancement of technology. Wide adoption of automation as well as modularization and standardization make basic parts widely available and often disposable. As we are already experiencing today, standard products are mass-produced in a few manufacturing centers and sold worldwide. These trends take away the bulk of local manufacturing jobs and put them in a few highly concentrated and specialized hands. Most engineers will focus on system integration, sales and customer service. In order to be competitive, engineers have to expand their knowledge base. To be relevant, they need to be sensitive and able to learn new and emerging developments in the technical and industrial horizons. They also need to expand their comfort zone from working with machines and numbers to working with people. They must understand the needs of their customers and be able to provide solutions, present these solutions, and oversee their adoption.

The introduction of ROV-based projects to engineering education is our endeavor to accommodate these trends. In Emerging Topics, the mechatronic project integrates the topics of Machine Design, Mechanical Design, Electronics, and Fluid Dynamics into one senior-level course. It also introduces the students to many frontiers of technology through their own research or their peers' papers and presentations. It emphasizes hands-on experience, and promotes teamwork. Meanwhile, in many capstone designs, students encounter major hands-on projects for the first time. In contrast, Rowan students already have intensive project management and fabrication experience in their Engineering Clinics. Hence, we actively promote communication and evaluation, which we consider most important.

Compared to similar courses offered elsewhere, there are many unique features in the Rowan ROV project due to different goals and scopes. For example, at Stevens Institute [11], the goal is to introduce design and foster creativity in freshmen. They use LEGO parts for easy implementation and frequent modification. By contrast, our goal is to simulate a realistic development environment to prepare seniors for their first jobs. Therefore, we require our students to follow standard industrial procedures, namely, paper design – CAD – structural analysis – machining – assembly – test – report.

Many programs focus on competition to promote productivity, creativity and collaboration. In our project, the competition only counts for about a quarter of the final grade. We put a lot of effort in encouraging effective communication and promote self-learning through a series of student presentations, written papers and peer reviews.

From the experience of the ROV class, some important lessons learned are:

1. As in any other project-based course, planning and logistics are extremely important. Common parts need to be ordered and stocked early, so the students will have a basic idea of what they will use. It also helps to prevent the waiting game or unexpected cost on overnight shipping.

2. For a school to offer the course for the first time, it is beneficial for the faculty to build their own ROV first using the same tools available to students. It will help set a more realistic schedule and pace for the class.
3. Once the schedule and milestones are set up, they should be firmly enforced. There is a natural tendency by students to push the hard work to the last minute. The result will be an exhausted group with a subpar product.
4. We need practice, practice and practice. A water tank or an empty sink in a project lab is handy for testing the individual parts. However, a real test in a swimming pool or a local lake is essential for success. Due to the three dimensional motion, unfamiliar view, and possible leaking, an ROV often does not behave as expected. Patience and endless adjustment are always required.

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