Undergraduate Research and Experiments in Robotics-Based Accomplishments for STEM Education

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Abstract
To retain students in the STEM fields, many universities have developed apprenticeship training programs using robotics. The inherent design challenges in building robots provide a context whereby the applied science and the knowledge from relevant courses is seamlessly integrated to solve the problem at hand while gaining interpersonal and critical thinking skills that can be transferred to professional activities following graduation. The Undergraduate Research and Experiments in Robotics-based Accomplishments for STEM education (URERAS) project has developed and implemented. The goal of this project has been accomplished through four specific objectives; (1) foster undergraduate research in robotics; (2) promote peer-to-peer learning in team-based, hands-on experiments; (3) develop and implement a new robotics curriculum; and (4) apply the principles of robotics design as a means of increasing the awareness of STEM careers.

Keywords: STEM education, robotics, robotics competitions, robotics in education.

1. Introduction

In recent years, the United States has been graduating fewer students with STEM degrees compared to other countries. One contributing factor is the low rate of retention within these degree programs at colleges and universities [4]. According to the report, “The STEM Workforce Challenge¹,” low engagement with STEM-related learning is one factor prompting many students to change their study to non-STEM programs. To retain students in STEM fields, many universities have developed apprenticeship training programs using robotics.

Robotics is an emerging multi-disciplinary area in STEM that combines mechanical, electrical and computer engineering in the design and construction of robots to perform specific tasks. Additionally, robotics emphasizes mathematics (for developing algorithms used in programming) and computer science (for programming the circuit boards). Building robots provides practical hands-on experience and develops crucial skills such as problem solving, communication, critical thinking and teamwork [6]. The inherent design challenges in building robots provide a context whereby the applied science and the knowledge from relevant courses (engineering, computer science, mathematics, etc.) is seamlessly integrated to solve the problem at hand while gaining interpersonal and critical thinking skills that can be transferred to professional activities following graduation. Verner and Ahlgren [10] identified specific mechanisms by which robotics effectively engages students in STEM education. They have shown that students acquire a holistic view of STEM subjects and gain essential knowledge and experience for success in advanced courses which then leads to both improved retention and classroom success. In addition, students participating in robotics projects are involved in self-directed interdisciplinary learning through research, design, teamwork, and professional communication. They learn about physical environments that a robot needs to navigate and human factors and also gain valuable experience in solving problems.

The goal of this project funded by EPSCoR Research Trust Fund (RTF) is to increase the number

of students graduating with computer science, mathematics and engineering degrees by 10% within 5 years. In order to accomplish this objective Shepherd University (SU) has developed and implemented an Undergraduate Research and Experiments in Robotics-based Accomplishments for STEM Students (URERAS) project. The URERAS project is fueled by a passion to provide students with opportunities to both learn about the benefits of STEM and to prepare them for careers and/or graduate training in STEM fields through robotics education and research. By building both unsophisticated and sophisticated robots in teams and participating in local and international competitions, students are going to become more engaged in STEM learning thereby increasing retention and positively impacting recruitment, both of which lead to increased numbers of graduates.

The URERAS project is designed to have a positive impact on the number of STEM graduates by increasing students who are recruited and retained in STEM disciplines at SU. The goal of this project is accomplished through four specific objectives. These objectives are to: (1) foster undergraduate research in robotics; (2) promote peer-to-peer learning in team-based, hands-on experiments; (3) develop and implement a new robotics curriculum; and (4) apply the principles of robotics design as a means of increasing the awareness of STEM careers. Participants in the URERAS project are mentored and trained to design, build, debug, and drive robots for specific tasks. They have developed skills and attitudes imperative for success in STEM fields both during college and following their college careers. While the focus is on STEM disciplines many of the skills (critical thinking, communication, team work) are applicable to all majors and correspond to the skills that business executives have identified as needing greater emphasis at the college level\(^2\).

2. Case Study: URERAS Project at Shepherd University

As shown in Figure 1, Shepherd University has implemented the URERAS project over three years. Within each of the four primary objectives, specific activities support the overall goal and the relative success is measured through assessing each activity. Each objective is discussed in more detail in the following subsections.

2.1 Undergraduate Research

The objective of this component is to increase the number of students participating in undergraduate STEM research. The benefits of undergraduate research are well known and include improvement in student learning, engagement and retention [8]. The Computer Science, Mathematics and Engineering (CME) department has already established an undergraduate research forum within the School of Natural Sciences and Mathematics that allows students to present their research results. As an affiliate of the West Virginia Space Grant Consortium, NASA fellowship awards have previously enabled Shepherd University students to conduct research, present and publish their papers in the annual “School of Natural Sciences and Mathematics Journal.” Over the past two years, faculty members have directly observed some of the expected outcomes of undergraduate research, most notably how participation in undergraduate research has enhanced student learning with a sense of excitement that had previously not been observed.

The undergraduate research component in the URERAS project expands upon the existing undergraduate research programs in CME. Students work more closely with faculty mentors in all aspects of research including project conception, design, implementation, analysis and publication of results. Some possible undergraduate research topics are decision making processes for contest robots, modeling and applications of sensor networks, human-robot interface, bio-robotics, and unmanned vehicles. As students work with research mentors, they gain discipline specific knowledge and learn to think independently and communicate effectively.

Undergraduate research is going to continue beyond the project period through student involvement in an undergraduate research club. In lieu of stipends, students may qualify for NASA fellowship funding and/or receive credit for partial fulfillment of course work for the research.

2.2 Team-based Hands-on Experiments

Numerous studies indicate that cooperative learning methods (e.g., having students work in small groups) can contribute to students’ learning of concepts and processes [3]. The hands-on experiments component can be built upon another of the existing strengths within the department, for example, robotics club, IEEE student chapter, and so on. In 2008 a group of students formed the Shepherd University Robotics Club (SURoC) with the assistance of the CME faculty. Since starting with three members, the club has grown and reached more than 30 members in five years. Members of SURoC have been active in software and hardware development since the club’s inception so the current members are familiar with the use and development of these materials as they relate to robotics. Members of SURoC have participated in a few regional and international Firefighting and Mechwarfare competitions as a part of the project activities.

This component provides various robotics experiences throughout a student’s academic career at the university. Figure 2 shows the robotics experiences for the first two years (see Section 2.3 for experiences of upper level courses). All students in the project have the opportunity to use at least 3 different robotics tools of increasing complexity. In order to ensure that students have ample opportunities to participate in these activities two courses (FYEX 102 Robots: Bots and Bits and ENGR 299 Introduction to Robotics) have sections dedicated to these activities. The first year experience course (FYEX 102) targets entering students while the ENGR 299 course targets sophomore students. The LEGO Mindstorm tool is used to develop fundamental knowledge of building robots in ENGR 299 which is a project- and team-based course that includes the active participation of up to three peer educators. Students in this class learn about the basics of modeling, design, planning, control and programming of simple robots.
It takes time and practice for students to function well in team roles. Faculty and peer educators guide the teams in one or more warm-up activities to help each student learn and understand his/her role in relation to other team members. This can be done in the freshmen seminar class (ENGR 100) which is offered every fall semester. In this course students learn that successful implementation of the design team is dependent upon three factors: (1) students know and understand the roles of everyone on the team; (2) students accept their individual roles and understand the responsibility of those roles; and, (3) students are willing to accept direction from other team members. Assigning these roles to students will prepare them for future career success.

2.3 Curriculum Development

The Computer Science, Mathematics, and Engineering (CME) department offers a variety of degree options including a B.S. in Computer Engineering (CPE), a B.S. in Mathematics (MATH), a B.S. in Computer and Information Sciences (CIS), and a B.S. in Computer Information Technology (CIT). Computer engineering is a rapidly growing but relatively new program at SU. To effectively bring engineering into the curriculum, it is essential that creativity, collaboration, communication, and standards of ethics be emphasized and infused throughout all projects. In this component the exposure of students to engineering practices early (during the freshman year) and often (each year of the program) will not only increase student retention but also technological literacy among the students. The improvements in technological literacy serve not just courses within the major but help students with decision-making in their academic careers.

To meet specific educational objectives, it is crucial that an engineering design concept and a problem solving process are introduced to the students early in their training. Four robotics-related courses are developed - ENGR 299, Introduction to Robotics (3 credits), ENGR 482, Embedded System Design (3 credits), ENGR 489, Engineering Capstone I (1 credit), and ENGR 490, Engineering Capstone II (2 credits). As seen in Figure 3 the course sequence encourages the retention and development of new knowledge and skills.

The proposed ENGR 299 course contains a laboratory using LEGO Mindstorm, a commercially available product shown to be an optimal tool for undergraduate level courses, from introduction to computer science class to advanced software engineering class [5] and computer engineering capstone projects. The program in Computer Engineering requires a yearlong sequence of senior capstone courses, ENGR 489 and ENGR 490.

These courses provide opportunities and ultimately pave the way for accomplishing a significant mission in STEM fields. Instituting a research experience through robotics activities benefits students not just in the classroom but through the skills necessary for the profession and the development of habits associated with lifelong learning. Throughout the courses students are prepared to pursue their personal journey as critical thinkers and problem solvers.
2.4 Applied Principles of Robotics Design

Fire-Fighting robots (FFR) are fully autonomous robots and MechWar robots (MWR) are remote-controlled humanoid robots. Both FFR and MWR are mechanically and computational more complex since they require augmentations such as an array of sensors and increasingly sophisticated algorithms. These robots are used in non-curriculum based experiments for SUROC members. Five different design teams, with five students per team, usually work on these two robots. Each robotics design team typically consists of one or two junior and/or senior students and three to four freshmen. Because many freshmen students lack either the necessary motivation or confidence to complete college and often have inadequate social support and/or role models [2, 11], forming a team with upper and lower class students helps overcome this problem and leads to greater academic success and persistence. Also, having a peer educator offers many benefits to all students on the team along a process of inquiry and discovery, and this process forces peer educators to engage with the material at a deeper level [7].

This activity includes organizing and participating in robotics competitions. Not only will these competitions provide an opportunity for students to demonstrate and test their robots, student participation can also spur excitement, motivate learning, and enhance the learning process [10]. The robotics competitions promote STEM field education through the application of knowledge and skills by providing meaningful student engagement, fostering economic development in the community through annual competitions at SU, and nurturing the development of lifelong skills useful in the classroom and work environment.

These annual robotics competitions, ShepRobo Fest (SRF)\(^3\), have two different contests, a Mech-Wars Contest (MWC) and a FireFighting Contest (FFC). The MWC is designed for a true walking robot with at least two but not more than four legs. Each robot must have a mounted camera and a weapon with a remote controller. The mounted camera is used to navigate the arena (15’x15’x8’ with obstacles). Matches are won by reducing the opponent score to 0 by successfully hitting the target mounted on the opposing robot. The Fire-Fighting Contest (FFC) is designed for a fully autonomous computer-controlled robot. The robot is required to navigate a maze (8’x8’ with 4 rooms), find a lit candle, and extinguish the flame in the shortest possible time. The task simulates the real-world operation of an autonomous robot performing a fire protection function in a real house. The goal of the contest is to advance robotic technology and knowledge while using robotics as an educational tool.

Robotics competitions provide a project-based learning method that engages students in many different ways. The ability to incorporate the students’ own design solutions encourages these students to take ownership of the project and often requires them to expand their knowledge base and skills. In addition, competitions have been shown to increase engagement in a way that is often hard to achieve in a traditional classroom setting [1]. Organizing robotics competitions at the university not only allows current students to demonstrate and test their skills but also helps recruit new students (high school and community college) to the STEM fields. At the same time, they promote economic development by attracting participants and their families to Shepherdstown.

3. Conclusions

In order to set the stage and establish a pipeline for future STEM students, it is necessary to make creative and accessible educational resources available to teachers and students through robotics [7]. Robotics is an excellent tool and a compelling topic for teaching STEM fields. This project provides an opportunity to share our experiences and expertise on robotics through curriculum development, research, and applied practice in competitions. Robotics experience-based activities propagate and maintain the resources and tools necessary for successful support of the project.

There are many STEM initiatives in the U.S. that have been exploring efforts to recruit and retain students. Such recruitment and retention strategies are critical for helping the U.S. improve its competitive advantage in STEM fields. The UERAS project at Shepherd with its series of activities in robotics is a first step towards bringing
excitement to a STEM education and promoting an interest in STEM careers.

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References


