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Engaging Students in STEM Learning through Co-Robotic Hands-On Activities (Evaluation)

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Engaging Students in STEM Learning through Co-robotic Hands-on Activities

Abstract

This paper introduces two co-robotic pedagogical platforms. The goal is to study the effect of meaningful learning contexts and hands-on activities, facilitated through the use of co-robotic platforms, in broadening and sustaining student engagement in STEM. The paper presents a week-long residential STEM learning curriculum designed and implemented to introduce students to hands-on engineering. The week-long program has been offered for middle school level students, and its effectiveness has been studied. Pre and post surveys have been conducted to study the impact of the experience in increasing students' interest in robotics and engineering. The results of this study show that co-robotic activities increased students' awareness about the role of engineering in protecting the environment and improving human life.

1. Introduction

Science teachers across the nation have to find innovative ways to incorporate the three dimensions of the Next Generation Science Standards (NGSS) [1] –Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas—in their classes. To respond to this urgent need, Nonlinear and Autonomous Systems Lab (NASLab) and Human-Interactive Robotics Lab (HIRoLAb) at Michigan Technological University have collaborated to create an educational program utilizing in-house educational co-robots.

The two co-robotic platforms are: 1) A Glider for Underwater Problem-solving and Promotion of Interest in Engineering or "GUPPIE" [2] developed by NASLab and 2) a surface electromyography (sEMG)-controlled manipulator called Neu-pulator developed by HIRoLab. The co-robots are easy and inexpensive to manufacture, with readily available lightweight and durable components. They are also modular to accommodate a variety of learning activities that help young students to learn about science, technology and, engineering.

During this program, students learn how the engineering process comes together and how robots can help people explore the environment and improve human life. Co-robots will help teachers to exploit the natural connection between engineering and science concepts. The activities are designed to attract the interest of students as early as middle school and sustain their interest through college, and thus learning can be scaffolded. Co-robots showcase the diversity of robotics application in engineering design. Students observe, practice, and implement their newly acquired engineering knowledge in two different fields of robotics: building a robotic arm to help a human with daily life activities; and manufacturing an underwater glider to collect water quality data in lakes and oceans to help the scientists with water pollution crises.

2. Background

This work intends to meet the challenge of stimulating and sustaining the interest of rural students in Science, Technology, Engineering, and Math (STEM). Moreover, this work targets the half of the population – women – that is underrepresented in engineering and STEM occupations. The introduced hands-on activities are aligned with the goals of NGSS framework and promote the engineering design process in K-12 education.

The NGSS framework was developed in an effort to produce K-12 science standards rich in content and practice that are coherent across disciplines.[3] The NGSS (2013) indicates that engineering must be a fundamental part of the new framework since students are required to develop the capability to carry and transfer knowledge across science disciplines through modeling, planning, conducting investigations, analyzing and interpreting data, and constructing explanations to demonstrate understanding of core science ideas. Students "must be able to apply scientific ideas to solve a design problem, taking into account possible unanticipated effects".[3]

Our approach to broadening participation is based on what we know works to engage girls in engineering. We know that precollege and college design classes have a much higher percentage of women, as do classes or competitions that are organized around a "Make Life Better" theme.[4-5] Middle and high school students, specifically girls, are interested in careers that "help" people and the environment.[6] There are practices focused on attracting girls to STEM such as EngineerGirl [7] and GoldieBlox.[8] Reaching students in the middle school years is critically important [6] because they are forming interests that, in the short term, will affect course selection in high school, and, in the long term, may affect career choices. To increase female enrollment in mechanical engineering, electrical engineering, and robotics, we need to promote engineering as a profession that contributes to the welfare of society.[9] Based on this knowledge, we strongly believe that if the scientific and human value of engineering is made clear to students during 6th -8th grade, we will significantly broaden engagement in critical STEM areas.

Variety of STEM educators promote STEM concepts through hands-on activities to multiple group ages. C-STEM center at UC Davis emphasizes on teaching programming, robotics and digital media through a self-sustained summer camp to 4 to 8th grade students, and targets middle school girls through Girls in Robotics Leadership camp. [10] In Carnegie Mellon University, Illah Nourbakhsh and his team in "The Robotic institute" developed K-12 educational outreach program to promote STEM concepts through hands on activities. His Women at SCS and Girls of steel interacts with middle school and high school girls to promote computer science and robotics. [11] His Arts and bots is a combination of crafting and common robotics programming that promotes collaborative "expression-focused robots" rather than competition based robotics.[12]

In our work, co-robots are introduced as pedagogical tools to utilize engineering design as a motivator to teach Science, Technology, Engineering, and Mathematics through practical hands-on activities to students. Engineering education assists development of engineering "habits of mind" including systems thinking, creativity, optimism, collaboration, effective communication, and ethical considerations.[13] This paper reports on the first year of a multi-year project to engage middle and high school students in the engineering process through co-robotic activities. The efforts include developing a hands-on curriculum, implementing it in a week-long summer youth program in summer 2015, and evaluating the outcomes.

3. The Engineering Process

Our goal is to engage students from early ages in engineering practice to learn the "engineering process". To increase the project impact, we plan to train teachers to be able to conduct these class activities independently. Studies show that many students are not exposed to the engineering topics during K-12 because their teachers were not trained to include engineering concepts in their course content.[14-17]

The NGSS framework defines engineering as any engagement in a systematic practice of design to achieve solutions to particular human problems.[3] Engineering practice as shown in Figure 1 is composed of six stages to create solutions. This engineering process includes ask, imagine, plan/brainstorm, create/build, test/validation, and improve/redesign.

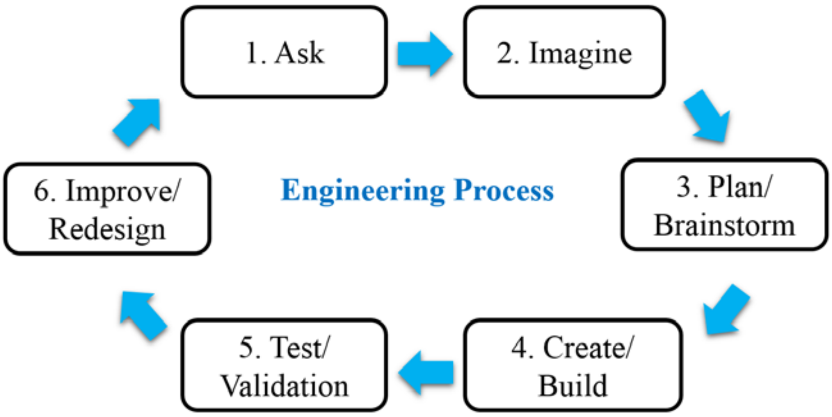

Figure 1: Engineering Process Concept.

The engineering process begins with identifying the problem and asking the right question. This step addresses the first component of the engineering core idea, defining and delimiting engineering problems. Following this step the creativity and problem-solving phase starts. To *imagine* the possible solution, one explores different aspects of the problem by utilizing different resources ranging from informative websites to journal papers and textbooks. At this stage students will learn how to evaluate the information they find on the Internet. Next, students brainstorm and analyze different criteria associated with the problem and the solution. Then they plan the project in terms of cost, time and deliverable. After designing and planning, they begin prototyping and production. The product goes through testing to validate the performance against requirements. If the requirements are not met, design improvement is necessary and steps 1-5 are repeated. Students practice these stages repeatedly to optimize the design solution. With GUPPIE and Neu-pulator, students experience the engineering process and learn how robots can help people and explore the environment.

3.1 Curriculum Development

The goals of this curricula is to develop: 1) a course content that aligns with the NGSS core concepts and promotes engineering design thinking in young students; 2) a program that prepares teachers to teach this content; and 3) affordable hands-on pedagogical tools that complement that course content. We select co-robots since they merge all the necessary concepts of science and technology into the engineering process. Students learn about basic programming to make their robot work. Unfortunately, coding and programming education is rare in the K-12 system.[18] Our aim is to develop a multi-disciplinary course that combines elements of electrical, mechanical, mechatronics and industrial engineering, as well as computer science. We develop platforms that can mitigate these difficulties and marry different aspects of the engineering process.

The NGSS framework identifies eight practices of science and engineering as essential for all students to learn[19] : 1) asking questions (for science) and defining problems (for engineering), 2) developing and using models, 3) planning and carrying out investigations, 4) analyzing and interpreting data, 5) using mathematics and computational thinking, 6) constructing explanations (for science) and designing solutions (for engineering), 7) engaging in argument from evidence, and 8) obtaining, evaluating, and communicating information. The co-robotics program covers these eight practices by dividing the course activities into five categories: 1) design 2) production 3) assembly 4) programing 5) test and validation.

The course starts with an introduction to robotics and the current state of the art in this technology. Students discuss how robots can affect human life and the surrounding environment. To familiarize students with the different components of the co-robots and their functions, students explore a pre-assembled GUPPIE and Neu-pulator. This discussion session engages students in the design process and taught them about the electronics, structure, and dynamics of the glider and the manipulator. The design process begins with brainstorming. Students and their instructors discuss how they could build a robot with provided affordable materials. Then students make a rough sketch of the robot design. After that, students learn how to use 3D design software to draw the structural parts of their robots. In this course, students have the chance to 3D print components of the co-robots. After assembling their robot, it is time to program the microprocessor. In the co-robotics course, students learn the basics of coding in C language and use it to program the Arduino board. At this stage, the mechanical and electrical parts of the robot are ready and students can test their robots, observe the outcome of their designs, troubleshoot, debug, and redesign if necessary by iterating the design process.

3.2 Evaluation Methodology

To evaluate the co-robots course, we adopted four different assessment methods: survey, in-class assignments and challenges, observation, and interview.[20] The first sets of surveys are collected before the students attended the program including writing an essay to answer questions about their background in robotics, their level of computer/coding skills, and their comfort level with teamwork. They are also required to complete an on-line survey on the first day of the class. The answers facilitate initial group assignments. In the pre-course survey students rate the level of their interest in different engineering process aspects in scale of 1 (very interested) to 7 (not interested at all).

In-class worksheets and in-class observation are used to evaluate the pedagogical effect on students especially their learning of STEM concepts and their engagement and teamwork. Students complete the worksheets and answer short or multiple choice questions regarding the course content activities every day. Depending on the session topic, the questions include brainstorming and drawing a sketch, calculating the error of measurements, or multiple choice or short answer questions of the course material. A psychology student researcher observes students during each session without interrupting action to evaluate the students' behavior and their response to the activities.

After completing the co-robots course, students complete a post-course survey and participate in a post program interview. The post-course survey assesses student interest in each course activity and how the activities increase students' confidence and interest in engineering and robotics. The post-course interview is useful for gaining more knowledge of their experience with the program.

The results of the post-course survey and post-program interview are compared to the pre-survey controlled data as an outcome of this work. The comparison and other evaluations assist us in recognizing the successful pedagogical practices and the ones that need improvement.

4. Curriculum Implementation Through Co-Robotics Summer Program

We successfully tested the co-robots with the different age groups and diverse underrepresented populations in collaboration with Western Upper Peninsula's Center for Science, Mathematics, and Environmental Education (WUPC) and Michigan Tech's Center for Pre-College Outreach.

In the summer of 2015, the co-robotics engineering practice course pilot was offered to 21 middle school students (grades 6th-8th). Students were divided into two main groups of ten and eleven students for each co-robot session. For each session students were asked to self-select as teams of two or three. This team size helped the students have the opportunity to achieve hands-on experience. Students in group one attended the GUPPIE session in the morning and Neu-pulator session in the afternoon. Group two attended the sessions in reverse.

We provided each student with a folder containing all the worksheets, course instruction, manuals, and extra paper for taking notes. We used the worksheets to evaluate students understanding on the subjects taught. At the beginning of each session, we would address the problems of the previous session.

In the *design* session, students learned how to use engineering software (compatible with age group). The training started from creating simple shapes such as line, circle, and rectangle. Then they proceeded with a more advanced toolbox such as creating a 3D object from a 2D sketch, cutting holes in the 3D object, using fillet and chamfer tools. They learned how to use different views in the software to observe their design from multiple angles. This session introduced students with visualization and brought their designs to life. To practice realistic engineering design, students were required to measure one of the structural components of the co-robots using a caliper. After recording the dimensions in the record sheet, students started modeling the part using their earlier design training. A step-by-step manual was developed to assist students with their design process. Students were encouraged to practice this assignment as a group activity. The goal of this activity, in addition to engineering design, is to promote brainstorming multiple ideas in a group and practice team work.

In the production stage, students gained knowledge about fabrication and assembly processes. They sent their designs to the 3D printer for fabrication. In this process, they learned how 3D printers work. They also could use the 3D printer for internal components of the GUPPIE and Neu-pulator components. Students also had the option to use plywood or cardboard to build the manipulator membrane and paint the parts. GUPPIE uses off-the-shelf material such as syringes and an acrylic tube on which students used cutting and grinding tools to prepare for the assembly (Figure 2). After preparing all the components, students assembled the robots following provided assembly manual. All students had the opportunity to build both co-robots. Students resolved challenges of the build process through discussion with their team and the assistance of instructors.

Figure 2. Students are building GUPPIE.

Students learned basic programming, using an Arduino learning kit and following an instruction manual. Students practiced building simple electronic circuits to turn on and off LEDs, and used a servo motor to translate linear motion to rotational motion, photo-resistors to measure amount of light, an infrared sensor to detect objects. Students learned how each component of the circuit works and how each part of the code affects the outcome of the project through hands-on learning and practice. For example, they could change the time interval of the LED on/off state to observe how fast or slow it blinks, or how they could change the servo motor speed. After accomplishing the goal of each project, students were encouraged to solve a more challenging project related to what they learned. We called these assignments “fun projects”. We observed that students showed a great interest in accomplishing the fun projects.

After finishing the basic programming, each group was asked to write a simple code and upload it on the Arduino board used on each co-robot. The consistency of the electronics and mechanical components used in both projects is the fundamental advantage of this course. Students could easily implement the design, production and programing skills they learned on two different robots with the common components (Arduino board, servo motors, resistors, battery). They uploaded the prepared codes to run their robots, and then iterated to debug the codes.

On the last day of the course, each team had the opportunity to test both co-robots. They deployed GUPPIE in the swimming pool and swam with it. Each group installed the Go-Pro with the 3D printed mount on the GUPPIE and recorded a short video while they were swimming with the underwater glider they built. Students tested Neu-pulator and showed that using their muscle signals they can perform different tasks (Figure 3). Students were challenged to use Neu-pulator to play volleyball against each other.

Figure 3. Students are testing Neu-pulator.

4.1 Survey Results

Assessing the worksheets, we realized that students had a better grasp of the course material whenever a hands-on activity or visual effects were used.

In the pre-course survey 45 percent of the students mentioned they liked programming and only 40 percent have had any coding experience. The post-course survey found that 80 percent of students “learned coding, how to work with circuits, and how Arduino board works”. The other 20 percent highlighted that they learned how to build a robot.

In post-course survey results, students showed higher interest in programming/coding compared to the pre-course survey. In fact, 50 percent of students expressed that coding and wiring were their favorite activities because “it is fun to create the little projects and the challenge of troubleshooting was pretty fun.” Another student responded “I liked building and programming robots because it was exciting”. Forty-four percent of the students found building and assembling the robots exciting. One student expressed that “it was fun designing something that could actually be 3D printed.”

As for least favorite activity, four students found coding confusing and challenging. One student did not like assembling the robotic arm and another student did not like modeling because “it's hard for me to get everything in place”. More than 50 percent of the students expressed that “they liked it all” or “I didn't have a least favorite part, it was all fun.” When asked if there was an activity that they couldn't conduct, 83 percent responded “no”.

In addition, as part of post-course survey, students were asked if they were to build a robot, what would you want the robot to do. The answers were grouped into three categories: capability, research/exploration, and helping people. Some responses fit in multiple categories. For example, “exploration and doing the jobs that humans can’t” would fit in all three categories. We observed an increase in robots helping people category overall. The words humans, helping, people, underwater research, lives were the most commonly used.

We also learned that, at the middle school level, students are highly interested in learning how to write code. Since coding could be intimidating for some students, we decided to use the “play and learn” and “parallel learning” approach with this aspect of STEM learning. As some believe that coding is the real T in STEM learning [19], the survey result encourages more focus on programming and integration of electrical engineering with computer science in the co-robot course so that students could play with electronics and circuits while learning how to code.

5. Conclusion and Future Work

The co-robotics program was successfully offered in the summer of 2015 to a diverse group of students. Students learned and practiced the engineering process through hands-on activities with GUPPIE and Neu-pulator. When students swam with their own GUPPIEs or played volleyball with the Neu-pulator, their enthusiasm and excitement were contagious. Hopefully, this is a sign that the program will spark continued creativity, ingenuity, and love of STEM learning.

The co-robotics pedagogy is aligned with NGSS. In this course, students *asked questions* about co-robots and *described* their application in human life. They *conducted research* on different designs of both co-robots, learned how to *measure errors* and how to *collect data*. Then each student *designed* the robots and *modeled* them in 3D design software. They assembled their robots in the *production* stage. Students applied algorithm and created codes to run their robots *using mathematical and computational thinking*. They learned how to test and validate their designs: troubleshoot, debug, and redesign parts of co-robots. In the "fun project" segment, they explained their solution to solve the challenge and *supported their solution with evidence*. Co-robotics program covered the eight practices of science and engineering with these hands-on activities.

The current efforts of NASLab and HIRoLab focus on creating pathways for teachers to adopt co-robot hand-on activities in classroom. During the course, we also addressed and resolved some common difficulties in engineering teams, including gender dynamics, miscommunications, misunderstandings, and other frustrations that emerge from teamwork. We realized that the co-robotics program was a successful experience when students noted, "There's a lot more to robots than meets the eye" and "I learned how to program and create living and real robot instead of just drawing a picture of one."

The co-robotics course is a multi-year program started in summer 2015. This course is part of the Michigan Tech's Summer Youth Program. Registration is open for 2016. The specific target groups for this summer are female students and students from rural, low socioeconomic regions surrounding Great Lakes. The pilot teacher training will be also offered in summer 2016. We have scheduled a workshop for local teachers in the spring to present the co-robotic course to recruit teachers.

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