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EFFECTIVE USE OF ENGINEERING IN TEACHING SECONDARY STEAM COURSES: A ROBOTICS COURSE EXAMPLE

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ABSTRACT

Global Learning Charter Public School (GLCPS) is an urban secondary school located in the city of New Bedford, Massachusetts. GLCPS educates students in grades 5 -12. It is a Title I school with over 74% of the student population on free and reduced lunch. Historically, only 60% of students graduating from New Bedford move on to postsecondary education. It is the goal of our school to change this and increase the number of students entering post secondary education and more specifically to increase their interest in STEAM (science, technology, engineering, arts, and math) fields.

GLCPS provides a unique educational experience where students demonstrate academic excellence and mastery of essential skills. These skills include: technology literacy, public speaking, global citizenship and arts exploration. Incorporation of STEAM (science, technology, engineering, art, and mathematics) is a continued goal for our school. After attending teacher educator training/professional development in engineering-based learning (EBL), we decided to create a robotics course, which fully embedded EBL into the curriculum. The goal of this robotics course is two fold: 1) Combine engineering, math, science, and art/creativity into one course; and 2) engineering-based learning can impact the way students learn STEAM principles, retain STEAM theory, and apply them to real world, relevant applications.

The purpose of this paper is to illustrate how engineering-based learning inspired and impacted the development of a robotics course in an urban, financially disadvantaged, secondary charter school. Specifically, we detail how the principles and tools of the engineering-based learning pedagogy affected the development and implementation of this robotics course. Lastly, we will demonstrate how EBL and the robotics course have changed student perceptions of science, engineering, and math.

Keywords: Robotics, Design, Engineering, STEAM

INTRODUCTION

In 2002 Global Learning Charter Public School (GLCPS) opened its doors to New Bedford students as Horace Mann charter school. In 2006, GLCPS became a Commonwealth charter school that focused on creating a culture of personalization with small class sizes and a family oriented, small school setting. GLCPS is a tuition-free public charter school that currently serves 474 students in grades 5-12. Our free and reduced lunch program supports over 74% of our students. With that said, the city of New Bedford also has a history of less than 60% of graduating students entering post-secondary education [1].

GLCPS is a full inclusion school. Students, families, faculty and administration work in partnership to tailor the curriculum to the needs and level of each student. GLCPS offers an engaging and stimulating interdisciplinary curriculum that is based upon the Massachusetts Curriculum Frameworks.

Our students learn team work ethics, develop technology skills in their coursework, build strong communication skills, and hone necessary skills to become productive and ethical participants in a global society. GLCPS offers a comprehensive academic program that affords a solid foundation for success in higher education and beyond. The school has a strong belief that a true "community" school should work in collaboration with organizations throughout the city of New Bedford and the South Coast Region of Massachusetts to increase student awareness of STEAM in the real-world. GLCPS aims to form partnerships with local organizations and utilize the resources of our region by incorporating these resources into our curriculum and instruction.

Similar to many other school districts, GLCPS students often have a limited understanding of how STEAM subjects fit into their everyday lives. This misconception can result in apprehension and shyness toward science and engineering courses. This perception or lack of understanding causes many students to choose liberal arts over the hard sciences. Unfortunately, due to the charter school implication, students are not required to take many hard science, math, and engineering courses.

In an effort to spur interest in these subjects, teachers from around New England attended CAPSULE a two-week teacher training program at Northeastern University during the summer of 2012. This paper documents and analyzes the impact of engineering-based learning (EBL) on the creation of a robotics course from the perspective of the teacher and her students [2-4]. We (the teacher and CAPSULE instructors) hypothesized that incorporation of engineering-based learning (EBL) in the creation of a new a robotics course will increase student interest in STEM fields [5-7]. We believed the course would help students realize how science and engineering fit into their world and how science and engineering builds "cool" things. Through after school science and robotics programs, students would provide continuous feedback through elicitations and discussions on their feelings toward STEAM subject content. Through optional enrollment, we also planned to monitor and track students' interest in entering STEM post-secondary education.

WHAT IS ENGINEERING-BASED LEARNING MODEL?

Engineering-based learning (EBL) is a methodology that enables K-12 teachers to create relevant real world application of curriculum for student centered learning. Students learn to apply the scientific principles and math concepts learned in previous core courses to identify and solve problems posed by the teacher. EBL encourages and promotes participation, organization, communication, and group ethics to design, research, and solve each real-world problems predicated on the present unit being taught. EBL utilizes the engineering design process to organize the process of solving real world problems.

EBL is mass customization for K-12 student learning of core math, science, and engineering concepts. EBL allows students to design and develop solutions to real world problems using known engineering models and design structures such as the engineering design process (EDP) and the capstone experience. EBL uses the well-known engineering design process as the structure for students to follow. EDP is a structured, eight-step, systematic, open-ended process that allows students to explore, within each step of the design process (see Figure 1). To encourage and reinforce student familiarity with EDP, we were given a poster to show and hang in our classrooms. We emphasized this process because we wanted to show students that they are capable of designing something and using the same process that is used in industry. Furthermore, the capstone experience allows students to take control over their learning [7, 8]. The EBL process and combined tools allows students to feel empowered and allows students to feel they have control over what and how they learn.

The capstone experience has provided students with a real-world problem that they had to solve. This new style of teaching pedagogy gave the students control in design and creativity of their solution with no distinct "roadmap". In particular, this experience showed our students that problems do not necessarily have a *right* solution, they have a *best-design* solution given the circumstances and constraints of that particular problem [9, 10]. Unlike doing or writing a traditional lab report, students were "chartering their own course" with limited guidance.

The final component of EBL is the design tool of computer-aided design (CAD). Although there are many different versions of 3D modeling tools, we were taught Solidworks™ due to its usability and interface [11, 12]. We have found that Solidworks™ user interface has the most intuitive learning curve for students to use [12].

With that said, project-based learning (PBL) is the more common and familiar term when it comes to teaching pedagogy. Many teachers use PBL to reinforce theoretical principles but without a structure, we have observed limited impact on student learning [13-15]. Unlike project-based learning (PBL), EBL was focused on student-centered learning. Typically, PBL is taught in adjacent to a lecture (i.e. the lecture drives the project) [16]. Although PBL is the predecessor to EBL, they are distinctly different pedagogies that have similar focus on reinforcement of theoretical principles. EBL primary focus is on using real-world environments and situations to educate students on STEM theory and principles.

Using teachers as a portal to student learning, EBL was taught and experienced by nearly one hundred teachers from the New England region. Through a two-week professional development program called CAPSULE (CAPStone, Unique, Learning, Experience), teachers were able to learn the EBL methodology and tools theoretically and experience them practically [7, 8]. As a result, teachers were better able to understand what the their students would experience, inclusive of the joys and frustrations of a new pedagogy.

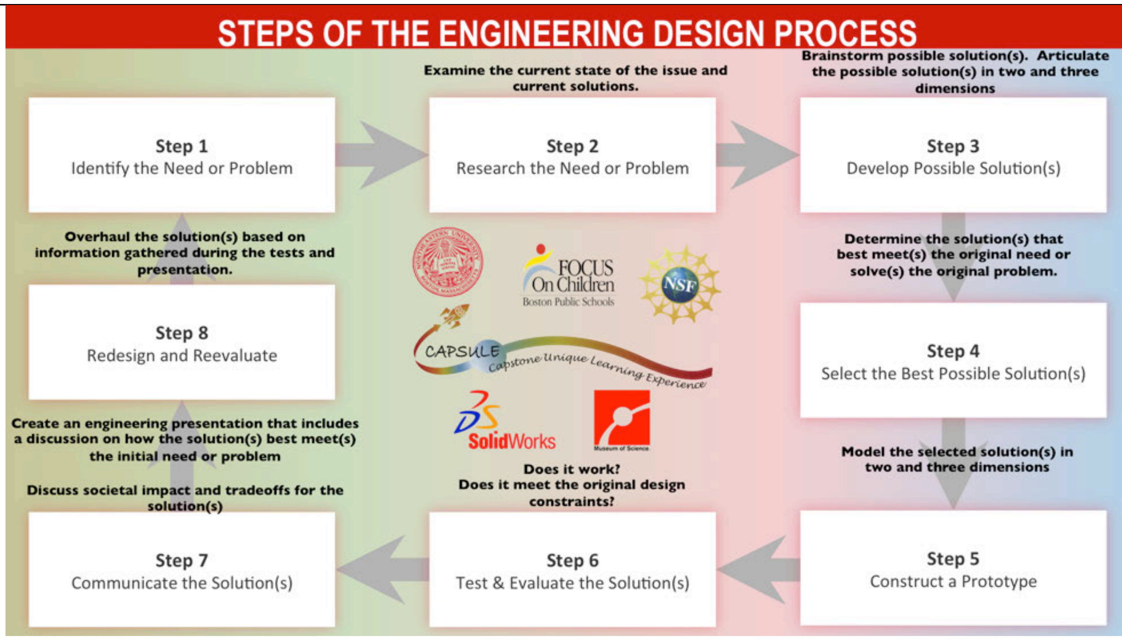


Figure 1: Engineering Design Process [7]

ROBOTICS COURSE DEVELOPMENT

As mentioned previously, the teacher training for EBL was obtained through CAPSULE at Northeastern University (NEU). The two-week summer program taught us hands-on experience with computer programs, lesson planning, engineering pedagogy, seed funding, and on-site support for course development and implementation. Although the robotics course for GLCPS was conceived prior to CAPSULE, implementation would have been significantly more difficult without the direction and guidance of CAPSULE and the education of EBL. During CAPSULE, the initial implementation plans for the robotics course design along with a course syllabus were presented to GLCPS administration for approval.

Curriculum design was focused on designing a robotics course that would attract students who were historically uninterested in math and science to this type of course. At the beginning of the CAPSULE program, we decided that EBL would concentrate on using EDP in a series of projects. Students would explore EDP by reverse engineering several existing kits and underwater ROV's. Students would webquest information on these products and use EDP to identify flaws in the current designs. The focus of this robotics course was to expose students to explore circuitry with snap circuit ROVS. Students would further their experience in the prototype design by using interactive computer assisted design and materials analysis through learning and using Solidworks™. The goal here was to expose students to the benefits of CAD engineering software.

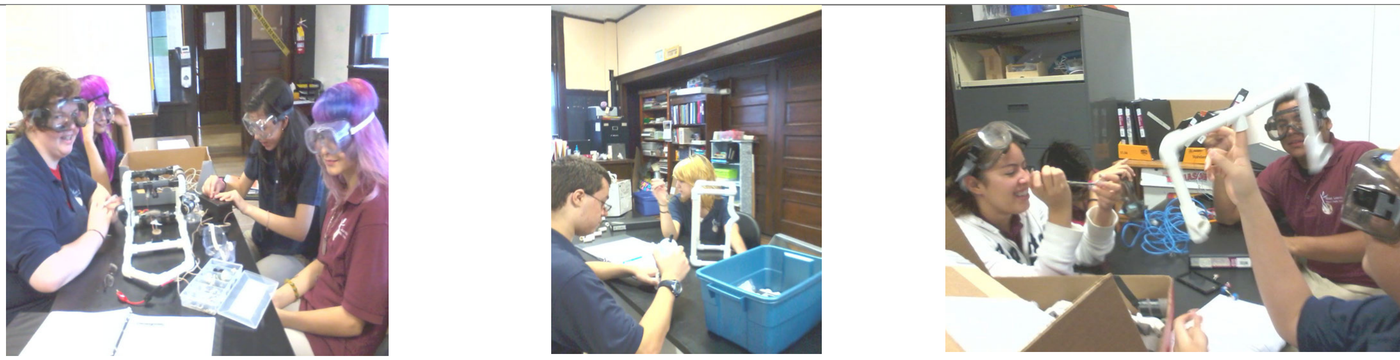
ROBOTICS COURSE IMPLEMENTATION

In the fall of 2012, GLCPS introduced two new semester course electives to the STEAM program. Both were hybrid robotics and EBL, engineering specific courses. The introduction of these courses was twofold: 1) Increase interest in STEAM amongst freshman and sophomore students; and 2) To improve student problem solving skills for both groups. The courses were an introduction to the engineering design process and how engineering can lead to various careers in math, science, and biotechnology. We had surveyed upcoming freshmen and sophomores in the spring to gather where their interests lie concerning science and engineering. The results of that survey indicated that students wanted a robotics program and would be more open to trying EBL courses if we offered one.

Through CAPSULE, we gained the necessary training and resources to appropriately design the curriculum. Because GLCPS is a tremendously underfunded school, resources are very limited. A major benefit of the CAPSULE program was the access to the staff. The staff from CAPSULE were available via e-mail and in-person scheduled visits to assist in implementation and co-teaching of the Solid Works design program. Through the partnership between CAPSULE and Dassault Systems, the parent company of Solidworks™, the software was available and used school wide; without this partnership, we could not afford the software otherwise.

Students began with a didactic program of studies introducing them to the EDP. As an introduction to EDP, students were assigned a project to build energy wind turbines from kits that contained purposefully inadequate instructions. As each team progressed through this build, they were to identify the flaws and create a report with recommendations for improvements. This initial project served a dual purpose: 1) It introduced students to EDP 2) They realized that there is no "perfect" plan or "perfect" product. Typically, there is a *best* solution based on the given constraints but no *perfect* solution.

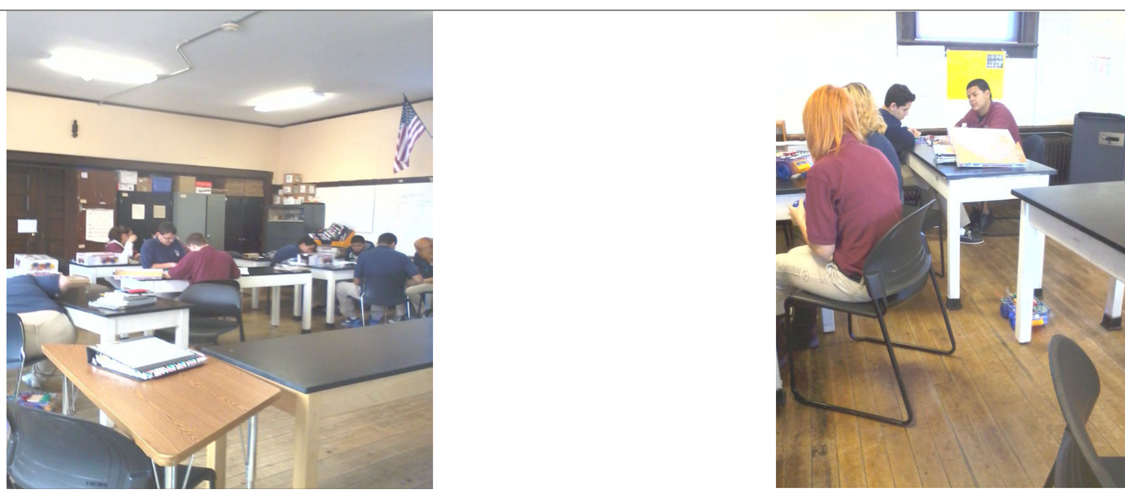
Their second project was the design of their robotic underwater vehicle. They were then presented with several webquests on underwater Remotely Operated Vehicle (ROV) designs. This project was to identify the proper use and construction of the underwater ROV. Students were then given the task to take apart and diagram the wiring for premade seaperch ROV and then report on whether these would pass a quality control inspection based off of their findings (see Figure 2).



(a) (b) (c)

Figure 2: Students Designing and Creating Remotely Operative Vehicles

A significant and unique aspect of this course was the continued thought process of design, build, and test. Unlike traditional courses, students also selected investigations on fields of engineering that involved insights into what, how, and where engineering occurred in their lives. Students were exposed to constant group meetings, collaboration, and student-run discussions. Students also kept journals of progress which contained reflections of their research into engineering careers, copies of project reports, and essays related to their design process and to each project they tackled (Figure 3). Students were able to record these sessions in their engineering binders for later reflection during their Presentation of Learning (POL) event at the end of the semester.

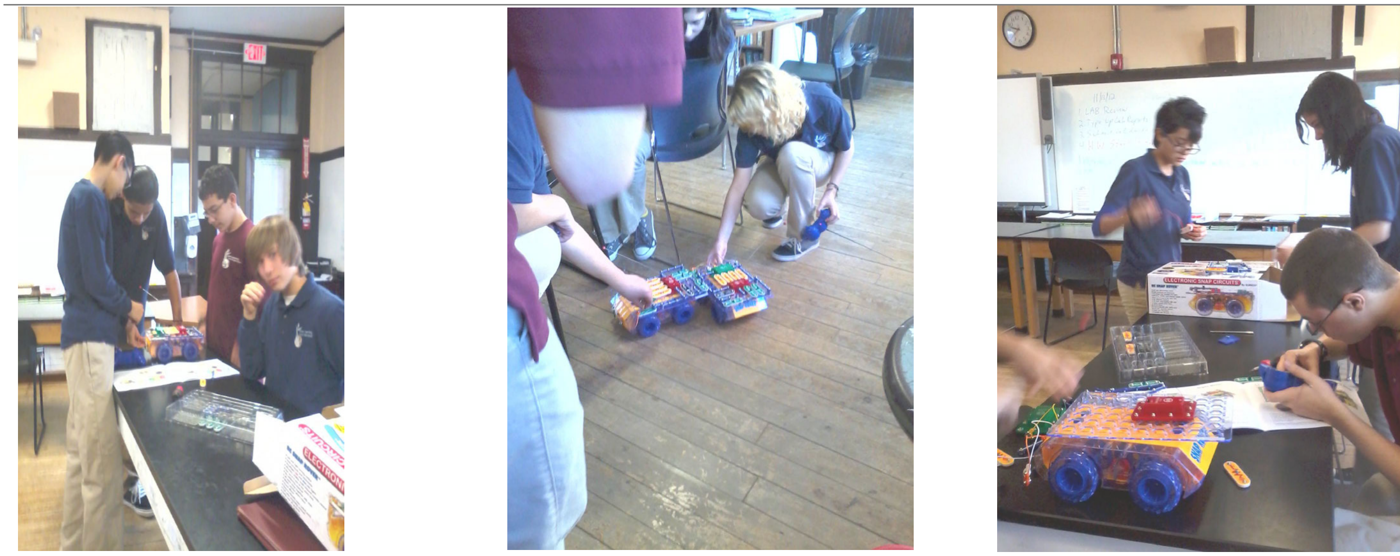


(a) (b)

Figure 3: Student Design Groups

Beyond the actual two-week professional development, CAPSULE provided us additional outside resources via group discussions in the summer program. The extended value of CAPSULE was the collaboration with teacher colleagues throughout New England. This particular resource allowed us to purchase Snap Circuit kits through a *Donors* Choose grant. Without our colleagues, this resource would have never been discovered. These kits were used to introduce students to circuitry and wiring problem solving (see Figure 4).

The value of snap circuit kits eventually led to students' interest in robotics. Students were exposed to the robotics environment and were instantly intrigued in the design and building of something that was operable. Robotics to them were no longer fictional – math, science, and engineering were real and were now attainable in their minds. Students began working on hand drawn orthographic designs of robots and robot parts for their final EBL project, the VEX robot kits. CAPSULE supplied the funds to secure the initial VEX kit. With the help of local students from Quinsigamond Community College, students were able to design and build a robot.



(a) (b) (c)

Figure 4: Students Using Snap Circuit Kits

Throughout the course we invited Bristol Community College instructors, engineering students, and industry volunteers from iRobot to speak with students about the application of engineering and robotics in real-life. We wanted students to connect what they were studying in the classroom to real-world applications. Most importantly we wanted them to realize that STEM careers are very possible for them to aspire to (see Figure 5).

(a) (b) (c)

Figure 5: Guest STEM Speakers

STUDENT RESULTS AND IMPACT

This robotics course has had a tremendous impact on a group of students that appeared to dislike school and appeared uninterested in anything academic. A student who took the robotics course in the fall asked if he could continue to be a part of the robotics club. The noticeable change in this student came, however, through overhearing a discussion with his peers. He proceeded to tell the other robotics club students how much he missed the robotics course from last semester:

"I wish I was still in that engineering course. It was so much fun and I really felt like I was doing real stuff. We got to decide what to build and how it would look. It was great!"

The true impact of this course cannot always be determined in grades or quantitative measurements. This student was unreachable, hated school, and based on observation, felt disconnected from his peers. The development of this engineering and robotics course has changed his perception of how he views math, science, and engineering.

Popularity of the robotics course has led to the creation of two after school robotics clubs. The high school club was started for students who could not fit the robotics course into their schedule. Further, the interest in the robotics club spurred interest in younger students in our middle school. In response to this middle school interest, we added a middle school robotics club. Not surprisingly, members from both have taken to attending both club days to help, mentor, and support each other despite the requirement to only attend one day.

As a result of the robotics course, the robotics clubs merged to compete in a regional robotics tournament as a direct result of the EBL implementation (see Figure 6). This spring we have a second session for the clubs and continue to add new members. While the club is popular, we have found that allowing flexibility in the days that we meet helps student attendance. A lot of our students can now go for extra help with academic subjects on one day and meet with team members the next. Students have recruited friends to join who could not fit the robotics class into their schedules. It also has served as a bridge for upcoming middle school students to explore STEM interests with our high school students in a common arena.

(a)

(b)

Figure 6: Students Robotics Regional Tournament

CONCLUSION & NEXT STEPS

GLCPS has been very excited about the incorporation of EBL into our curriculum. Student interest has encouraged teachers to inquire about EBL training for cross curriculum lessons. Presently we are working with Northeastern to create a teaching tool that could be used by other districts. We are continuing to collaborate and create partnerships with other schools, industry, and postsecondary institutions to offer sustainability for this course. We are also within GLCPS working on incorporating EBL at the middle school level as an introductory for our high school programs. We will be creating more engineering courses and integrating more engineering in core classes in the future. Our chemistry teacher who also attended CAPSULE last summer will be introducing his engineering course as part of our continued use of what we learned from the CAPSULE program. Lastly, our administration is currently budgeting for further teacher professional development and the incorporation of some type of "maker program" for our students. We have looked at many engineering curriculum program materials including Project Lead the Way. While this is a well-designed curriculum, the cost is prohibitive at this time. Funding for teacher training, substitutes, materials, and student workbooks is not available. However, we are using supplemental materials from the Boston Museum of Science and the Northeastern University Center for STEM.

The response to the robotics course has had overwhelming support and feedback from students and administrators. We hope to continue this momentum and foster a more collaborative, creative, and engineering-centric focus for our students at GLCPS.

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