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Teaching Middle School Mathematics through Robotics Project-Based Learning

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Abstract: *This paper discusses the use of robotics project-based learning in the middle school mathematics classroom and the mathematics that is currently being taught in robotics programs both in the classroom and outside of the classroom. Two robotics program mentors were interviewed about their experience with three different robotics' programs, one in-school and two after-school programs. The similarities between the concepts and teaching methods are discussed in the two different robotics programs. The mathematics concepts that the mentors developed in their respective programs are provided. Finally, suggestions are made for further research in the areas of student academic achievement in robotics project-based learning programs.*

INTRODUCTION

In recent years there has been an increase in the use of robotics project-based learning in schools through a variety of programs such as, VEX Robotics, FIRST (For the Inspiration and Recognition of Science and Technology) Robotics and LEGO® MINDSTORMS® (Bartholomew & Furse, 2015). In the VEX Robotics program, middle level and high school students are given a yearly challenge, and must design, build, program, and drive a robot to complete the challenge as best as they can. The FIRST Robotics program includes teams of middle and high school-aged students who are challenged to design, build, and program a robot to play a floor game against other teams' creations. LEGO® MINDSTORMS® is a hardware software platform produced by Lego for the development of programmable robots based on Lego building blocks. The reason for the increase in robotics instruction can be attributed to schools' and private companies' desires

to increase the number of students who can solve technical problems and create technological advancements that improves lives (Robinson, 2014).

Robotics can be used to teach a wide assortment of skills and concepts found in Science, Technology, Engineering and Mathematics (STEM) fields. Some topics in mathematics can be more easily taught through robotics project-based learning than others. Although teachers may want to implement robotics project-based learning in their classrooms they may not be comfortable with the technology or the mathematics required (Cejka, Rogers & Portsmore, 2006). Mathematics teachers may have difficulty determining which topics can be easily and efficiently taught using robotics project-based learning. Teachers' discomfort with robotics and the difficulty in creating lessons around robotics may discourage teachers from using robotics project-based learning in their classrooms. In addition, the unavailability of funds to cover the cost of purchasing robots can be a limiting factor in some classrooms. Fortunately, many robotics programs that are not run with the intention of teaching mathematics concepts do end up teaching mathematics topics because knowledge of a mathematics theorem is required to complete the intended goal of the robotics program.

The purpose of this research study was to explore how teachers in robotics programs integrated mathematics concepts into their instruction. Two research questions guided the study:

1. What mathematics topics and/or concepts do teachers develop in their robotics programs?
2. How do robotics teachers integrate mathematics in the classroom?

REVIEW OF THE LITERATURE

Project-Based Learning (PBL) is a constructivist teaching strategy in which students collaborate with their peers to complete a project to allow the students to use and reflect on their learning (Kizkapan & Bektas, 2016). Constructivism is an approach that expects students to assemble and interpret new knowledge, instead of memorizing (Kizkapan & Bektas, 2016). So by conducting the investigations, having the conversations or completing the activities necessary to complete PBL a student is learning by building on their current knowledge and adding new knowledge (Grant, 2002). PBL can increase students' interests in STEM fields because students are engaged in solving real world authentic problems, as well as working with others and creating real solutions (Laboy-Rush, 2011). The explorations in PBL begin with the end product in mind, and as such use a production model, and therefore mirror the real world production model (Remijan, 2016). In addition, PBL improves students' meta-cognitive skills so that students are able to make successful plans and evaluate their solutions. Also, PBL creates a more equitable learning environment and so contributes to students' academic success (Kizkapan & Bektas, 2016).

When teachers implement Project-Based Learning in the mathematics classrooms the students' motivation often increases because the projects empower students, the projects are thought provoking to the students, and the students are invested in the results (Remijan, 2016). Studies on the impact of STEM PBL have shown that lessons including STEM PBL increase students' positive attitude toward STEM fields and improve students' mathematic academic achievement. Han, Rosli, Capraro and R. Capraro (2016) found that PBL improved students' mathematics scores in the areas of algebra, geometry and probability.

Robotics lessons can be implemented at all grade levels and used to teach a variety of STEM related topics. For example, robotics can be used to teach students about functions by asking students to program the robotics to travel in the pattern designated by distance-time graphs, the students are only able to program robots to meet the requirements of the graphs that are functions (Fernandes, Ferme & Oliveira, 2006). The Center for Engineering Education Outreach at Tufts University has worked to bring robotics into K-5 classrooms by training teachers, providing classroom support and developing robotics curricula for all elementary grade levels (Cejka, Rogers & Portsmore, 2006). Robotics programs help students meet STEM objectives and develop critical thinking and "soft skills" (Bartholomew & Furse, 2015). There are some challenges with implementing robotics curricula and robotics programs, including teacher ability, limited technological resources and interpersonal struggles (Bartholomew & Furse, 2015).

For this paper the researcher interviewed two women who ran two extracurricular robotics programs and one in school robotics program. The purpose of the interviews was to learn more about how these women used and taught mathematics in their robotics programs. (See Appendix A) The mentors were both involved in the FIRST LEGO League (FLL) robotics program and both had a background in STEM fields. The women will hereafter be referred to as mentors because mentor is FLL's official title for its adult volunteers and because mentor accurately describes both women despite their differing STEM education backgrounds and experience. One of the mentors is a teacher, and also teaches classes involving robotics. Before becoming a teacher this mentor worked in computer science. The other mentor home schools her children, has studied mathematics and engineering and has experience applying those concepts to real world problems through her work flying helicopters. The FLL robotics programs consisted mostly of students in middle school. The in-school robotics program consisted of sixth and seventh grade students.

RESULTS

All three of the robotics programs, both FLL programs and the in-school program, developed mathematics concepts. The mentors talked about a variety of mathematics concepts, all of which were taught in context of solving momentum problems (See Table 1). The most common examples given by the mentors involved momentum and forces. In the FLL program the students are given a set of challenges and a time limit, the students choose which challenges to complete in order to get the most points. The mentors described how students learned about momentum while

trying to lower an arm to drag something and having the arm bounce, or about forces when the robot ran into an object with too much or not enough force. Although the students did not use momentum formulas they were using expressions, numerical constants, symbolic names, and mathematical operations, and functions in a formula according to one mentor.

The in-school robotics program used spherical robots (mobile ball-shaped robots with a spherical external shape) and the students applied momentum concepts as well, when they had to make the spherical robot stop rolling. The students use a C-based programming language for middle school and they write code for the robot to go straight, stop, change color along the way, and make ninety-degree turns. Both mentors also mentioned using angles. The mentor of the in-school program gave an example of using protractors to measure angles and help students determine how much their robot needed to turn. This discussion led some students to ask if they could use decimals to get a more accurate ninety degree turn from the robot.

Speed and rotation were also discussed by both mentors as mathematics concepts that their students explored while building and programming robots. One mentor talked about how she had asked students to consider different ways to measure a distance, including using a wheel and rotations. The other mentor gave an example of using rulers to measure rotations but added that usually the students experiment and figure out rotations and measurements on their own. The mentors both discussed how visualizing and examining mathematics concepts like angles gave the students a better understanding and made the concept more concrete for the students. The curriculum engaged students meaningfully in STEM concepts with the mathematics instruction integrated as the need arose from the students. One teacher stated, "…[the mathematics] it sort of takes it from being abstract something out of a textbook that they [students] actually get to put to work" and "they [students] use math that is the important part." In the after school programs the students are not formally assessed on their projects. However, the students compete in regional competitions and if they score high enough the students participate in state level competitions. (See https://www.vexrobotics.com/vexiq/education/iq-curriculum for example lesson plans and complete units in robotics for middle level students.)

In the FIRST LEGO League (FLL) robotics program the teams are assessed in the areas of Robot, Research Project, and Teamwork. (See https://www.first-lego-league.org/en/general/evaluation.html for additional information.)

Table 1

Mathematics concepts taught in the context of robotics momentum problems.

Mathematics concept	Number of mentors who taught the concept
Acceleration	1
Angles/degree measure	2
Deceleration	1
Decimals	1
Force	2
Logic	1
Measurement	2
Momentum	2
Percentages	1
Rotation	2
Speed	2

Both mentors taught student-driven robotics programs. This aligns with FLL's values and both mentors said that the students have been successful with this approach. Since the programs are mostly student-driven the mathematics the students learn and explore is also student-driven. As a result, there was minimal explicit teaching of mathematics concepts; instead mathematics concepts were addressed when the students encountered the concepts on their own. Also, both mentors used questioning techniques to help students discover their own solutions and the mathematics concepts behind the solutions. Both mentors talked about asking students' questions like "What happened?" "What was supposed to happen?" and "How can we change something in order to make that happen?" While the mentors both reported that using the mathematics concepts to solve real problems helps cement the concept for the student, they were not sure if using mathematics in the context of robotics increased students interest in mathematics. One mentor said that she was not sure if her students even realized that they were doing mathematics.

DISCUSSION AND FUTURE RESEARCH

Implementing robotics lessons into a mathematics curriculum may be challenging for some classrooms because of the cost of the robots. The results from this study of three robotics programs, recommend designing lessons around concepts that students in robotics programs are encountering naturally. By creating robotics PBL lessons around concepts such as speed, momentum and angles, mathematics teachers can engage students in real problems that the students enjoy solving.

An area for further study is how robotics PBL impacts students academically in mathematics. Research should be done to determine if teaching students' robotics does in fact increase students over all mathematics achievement abilities. Also learning more about students' attitudes towards mathematics taught through robotics would be another area for future research.

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