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Transforming a Middle and High School Robotics Curriculum

Ms. Mercedes M McKay, Stevens Institute of Technology (SES)

Mercedes McKay is Deputy Director of the Center for Innovation in Engineering and Science Education (CIESE) at Stevens Institute of Technology. She has led several national and statewide K-14 teacher professional development and curriculum development programs in STEM education. McKay is co-PI and Project Director for the NSF-funded Build IT Scale Up project to develop and disseminate an innovative underwater robotics curriculum for middle and high school students. She is a former practicing engineer with high school science and mathematics teaching experience.

Dr. Susan Lowes, Teachers College/Columbia University

Dr. Susan Lowes, Director of Research and Evaluation at the Institute for Learning Technologies at Teachers College, Columbia University, has conducted research at both university and K-12 levels, with a focus on STEM learning and on the impact of different technologies on teaching and learning. She has directed evaluations of multi-year projects funded by the U.S. Dept. of Education and the National Science Foundation,including ITEST Strategies and Scale-Up grants, as well as GK-12, MSP, and BPC projects. Dr. Lowes has co-authored papers and presentations on STEM learning in the sciences, engineering, and mathematics, including, most recently, ”Robots Underwater! Learning Science, Engineering and 21st Century Skills: The Evolution of Curricula, Professional Development and Research in Formal and Informal Contexts,” in B. Barker, G. Nugent, N. Grandgenett, and V.I., Adamchuk, eds., Robotics in K-12 Education (Hershey, PA: IGI Global, 2012).

Dr. Lowes is also Adjunct Professor in the Program in Computers, Communication, Technology, and Education at Teachers College, teaching courses on methodologies for researching technology in education and on online schools and schooling.

Ms. Devayani Tirthali, Institute for Learning Technologies, Teachers College, Columbia University
Ms. Elisabeth W McGrath, Stevens Institute of Technology (SES)

Beth McGrath is Executive Director of the Center for Innovation in Engineering and Science Education at Stevens Institute of Technology.

Mr. Jason Sayres, Stevens Institute of Technology

Jason Sayres is responsible for teacher training and developing Internet-based curriculum materials. He has a B.E. in Engineering Physics from Stevens Institute of Technology and an M.S. in Applied Physics from Columbia University.

Karen A Peterson, EdLab Group

Karen A. Peterson, M.Ed. is the Chief Executive Officer for the EdLab Group. Currently, she is the Principal Investigator for the National Girls Collaborative Project, SciGirls – A New National TV Series, the Computer Science Collaboration Project, Bio-ITEST: New Frontiers in Bioinformatics and Computational Biology, and Build IT Underwater Robotics Scale-Up for STEM Learning and Workforce Development (BISU) Project, all of which are funded by the National Science Foundation. These projects all address gender, racial and socioeconomic underrepresentation in science, technology, engineering, and mathematics (STEM) fields. Peterson serves on local, regional and national boards which develop and administer programs designed to increase underrepresented students’ interests in STEM. Peterson has published in The Journal of Women and Minorities in Science and Engineering and has co-authored evaluation reports and promising practices reports in informal information technology education for girls for the National Center for Women & Information Technology and the Girl Scouts of the USA. Peterson has also managed U.S. Department of Education grants designed to provide professional development opportunities to Puget Sound area teachers.

For over 20 years, Peterson has been active in education as a classroom teacher, university instructor, pre-service and in-service teacher educator, program administrator, and researcher. Serving as Western Washington University's first "Internet Librarian," she assisted teacher education faculty and students in the integration of technology into K-12 classroom teaching. She currently serves on the board of TrueChild, a research and action center devoted to challenging and transforming gender stereotypes and their impact on young people so they achieve their full potential. A graduate of the University of Washington, Bothell campus, her Master's thesis focused on gendered attitudes towards computer use in education.

Transforming a Middle and High School Robotics Curriculum from Formal Classrooms to an Informal Learning Environment: Strategies for Increasing Impact in Each

Abstract

This paper will examine a robotics curriculum that is impacting educators and youth in both formal, middle and high school classrooms as well as in a variety of informal learning environments. We have made comparisons between formal and informal learning environments in an effort to understand the varying impacts of this novel program on student learning of science concepts, their skills and abilities in applying engineering design and problem-solving, and their awareness and interest in engineering careers and the individuals who pursue these careers. Data from teachers, informal educators and youth during the second year of project implementation suggest that strategies designed to improve the experience and learning of participants in informal learning environments ultimately improve the enjoyment, content learning, STEM interest and engagement of students in both informal and formal environments.

Introduction

The similarities and differences between classroom-based science, technology, engineering and mathematics (STEM) experiences and informal programs extend beyond time- and place-based concerns. Issues such as content preparation of formal and informal educators and differing emphases on learning vs. motivation are factors impacting the design of the curriculum, professional development, and educator resources. Formal educators need to ensure that classroom time advances students' STEM learning in valid and measurable ways. Informal STEM educators also seek student learning impacts; however, engagement, motivation, and enjoyment are high priorities. Formal educators are constrained by classroom time available, state standards, and the pressures of high-stakes testing, while informal educators have greater flexibility, and often minimal responsibility in these areas. While the content expertise and preparation of informal STEM educators varies widely, from motivated volunteers with high degrees of STEM expertise to generalists with little STEM background, it is the case that a percentage of informal educators are, in fact, formal classroom teachers in their "day job." The differing curricular and program implementation goals, contexts, and needs of formal and informal educators are examined in this paper through the lens of a scale-up grant working to implement and adapt a robotics curriculum in both formal and informal learning contexts. Our study will describe strategies employed to transform an existing and proven curriculum from use in a formal classroom environment to informal summer camp programs and will examine student outcomes resulting from these different teaching environments. Note that throughout this paper the term "teacher" refers to formal educators and the term "educator" refers to informal educators.

Background

WaterBotics® began as a project to scale up a previous research effort that developed an underwater robotics curriculum by expanding the program from one environment (formal education) to an additional environment (informal education). The initial program, which was developed under a National Science Foundation Innovative Technology Experiences for Students and Teachers (ITEST) grant, engaged middle and high school students in a series of problem-based design challenges that required teams of students to work together to design, build, program, test, and redesign underwater robots made of LEGO and other components. Over two years of this initial program, 65 middle and high school teachers from 30 socio-economically and academically diverse schools implemented this 25-30 hour curriculum in a variety of classroom settings, including science, mathematics, technology education, pre-engineering, and computer science courses, and with selected groups of students, including academically homogenous as well as academically diverse groups, with gifted students, and with special education students. Teachers faced a number of challenges in order to expose their students to this complex engineering design curriculum, including their own level of relevant content knowledge and experience, time, facilities, equipment, and classroom management constraints.[1] Lessons learned from the initial project have informed the development and implementation of a scale-up project in four U.S. cities, including formal settings (e.g., traditional classrooms) and informal settings (e.g., summer camps). Further modifications and adaptations necessary to successfully implement the program in informal settings have been made as the scale-up program proceeds.

Robotics offers an exciting and engaging context for students to learn science and engineering concepts and skills, as well as an educational strategy to increase students' excitement and motivation for pursuing STEM careers. A growing body of research suggests that problem-based learning, engineering curricula, and "design-based science" are effective means of increasing students' conceptual understanding of science, their long-term retention of learning, and their abstraction or transfer of learning. Several studies conducted at the middle school level indicate that design-based activities result in significant gains in student understanding of science concepts[2, 3] and science skills[4]. Studies conducted in high school science classrooms using design-based curriculum provide evidence that these activities result in significant gains in student understanding of science concepts.[5, 6] Several studies[7, 8, 9] have also documented the impact of educational robotics on student learning of STEM concepts in informal learning environments.

Early in the development process of the scale-up grant, project partners – both formal classroom partners and informal education partners – met to review the curriculum in detail and discuss changes and adaptations necessary to implement the curriculum in a new teaching and learning environment, namely informal summer camp experiences that would be implemented by all partners and also informal education experiences specifically targeted to girls. Partners recognized the goals, structure, and emphasis of a summer camp experience would be different from the classroom experience and explored options for ensuring success in both, while also ensuring that research-based strategies for engaging girls in STEM would be included. Ultimately, partners recommended that two versions of the curriculum be developed; one for traditional classroom implementation and the other for informal education experiences that would have a greater emphasis on engagement with engineering and more interpersonal interaction among youth.

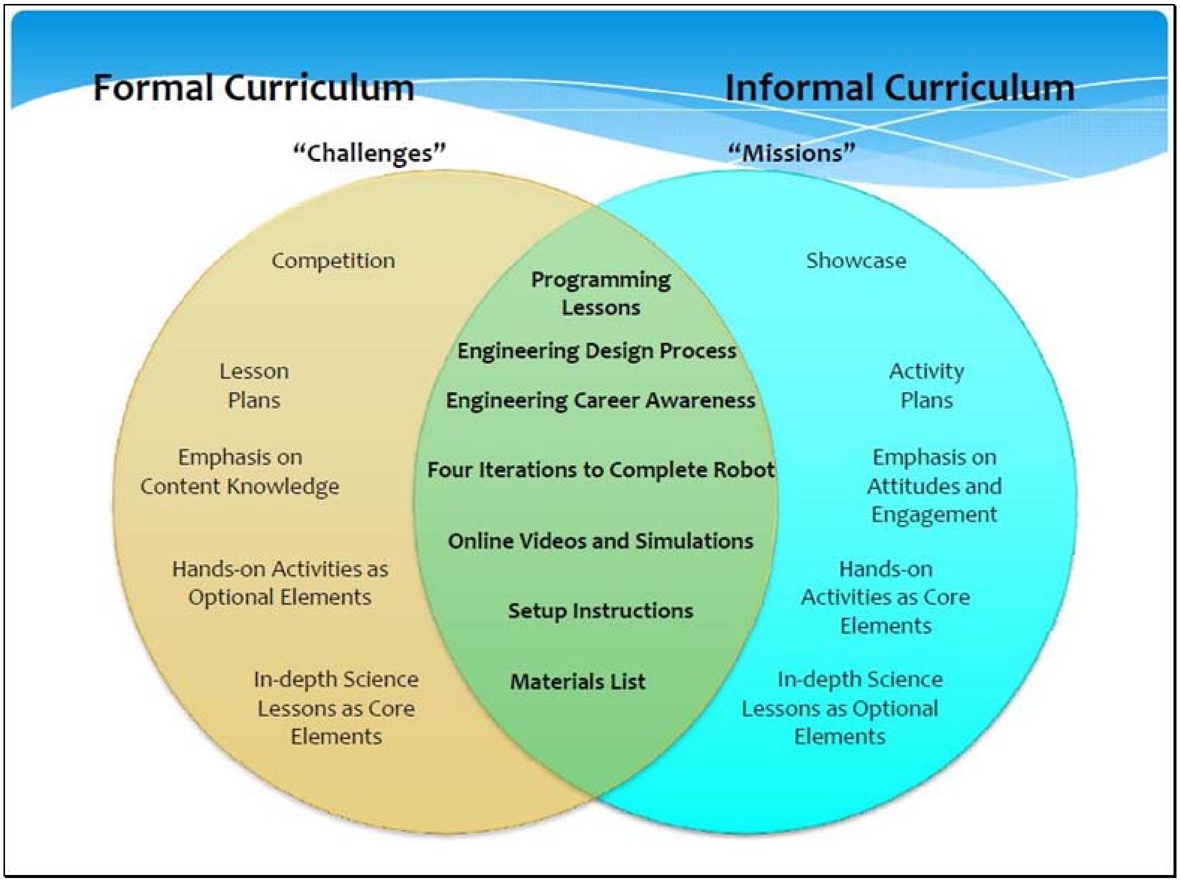
The project had its first year of implementation in 2010-2011 at one formal and one informal hub site. The formal (in-school) implementations took place during the 2010-2011 academic year, and the informal (summer camp) implementations occurred during the summer of 2011. Sinclair Community College in Dayton, Ohio, was the site facilitating the teacher training and in-school implementations and the Texas Girls Collaborative Project, based at the University of Texas, Austin, was the partner facilitating the educator training and summer camp implementations. During the second year of implementation (2011-2012), these two sites facilitated a second round of implementations while two new sites joined the project —Triton College in River Grove, Illinois, and the Pacific Northwest Girls Collaborative Project in Seattle, Washington — and facilitated trainings and implementations at their respective sites.

This study examines the impact of the program on student interest/engagement and on content learning in science and engineering in both formal and informal environments during the second year of implementation in this five-year program because it was during this second year that all four hub sites implemented the program. The study's original hypothesis was that the informal sites, primarily targeted to girls in camp settings, would have greater levels of interest and engagement while students in traditional classroom settings would score higher in learning.

Curricular and Professional Development Adaptations

Adaptations to the curriculum and the professional development model which, in a prior research effort emphasized developing teacher expertise to effectively deliver the curriculum, were revisited to adapt to the needs, constraints, priorities, and expectations of informal educators. The design of the curriculum; the professional development objectives and model; the type, frequency, and format of educator and youth assessments; and the availability and use of supplemental resources and online supports and community building are areas we have addressed in adapting the robotics program for effective implementation in informal programs. Through this process, the formal curriculum was modified and enhanced with the addition of engaging strategies and relevant content to facilitate its use in such contexts as summer camps, after-school programs, and programs particularly targeting girls. These changes are based both on the research on informal science learning and on research on gender in STEM equity, as well as our and our partners' experience. [10, 11, 12] Partners further developed what we have termed the "core elements of success," those aspects of the curriculum that have been correlated with significant student outcomes as shown in Figure 1. The core elements have been retained but presented in differing forms in the two versions of the curriculum (the formal and informal education versions). Both versions contain the same essential design challenges, use the same equipment and resources, and emphasize engineering career awareness. The informal educator version contains more specific instructions to guide educators through the curriculum, eliminating some aspects of the curriculum, using more accessible terminology, and including more STEM career resources and fun hands-on activities to complement the existing curriculum. The recommended amount of time to spend implementing the curriculum is 25 – 30 hours. The curriculum was designed with four challenges or missions, with three considered the minimum to be completed to ensure fidelity of implementation among all partners.

Figure 1: Core Elements of Success



The strategic changes made to the curriculum fall into different and sometimes overlapping categories that correspond to how students and teachers/educators will be ultimately impacted. What follows is a description of the changes made to the curriculum that project partners felt would impact student enjoyment, learning, interest and engagement in STEM fields, and fidelity of instructor implementation. The anticipated area of impact is noted for each strategic change.

Real-World Contexts

Anticipated Impact: Student Enjoyment, Learning, & STEM Interest/Engagement

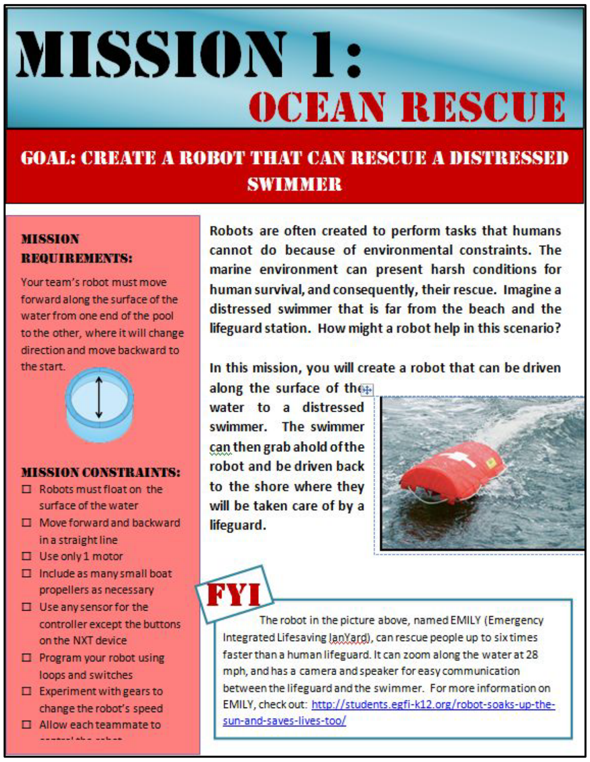
Each of the four design challenges within the curriculum were re-named as “missions” and enhanced by providing a connection to a real-world application of underwater robots. For example, in the first mission instead of creating a robot to go back and forth for its own sake, the context is to create a “lifeguard” robot that can go out to sea, reach a drowning person, and pull him or her back to shore. Based on an actual robot, this application becomes more immediately relevant to participants. Revised graphics and material presentation were developed to be more appealing to students. An example mission briefing is shown in Figure 2.

Additional Implementation Strategies and Step-by-Step Guides for Informal Settings

Anticipated Impact: Student Enjoyment; Fidelity of Teacher/Educator Implementation

Since most participants may not have previously met one another in an informal project implementation, they need a chance to get to know each other and to help group members bond and work together effectively such as ice-breakers, team-building, and brainstorming activities. Additional activities for “down time” also provide necessary mental breaks during all-day camp programs. Additionally, it may be the case that some informal educators lack a strong STEM background or experience with robotics programs and would benefit by having more structured preparation and implementation materials such as step-by-step guides for conducting the activities, example scripts of how to explain certain concepts, and more precise schedules of all the daily activities. Although these changes were originally developed specifically for the informal education environment, many have been incorporated into the formal classroom version of the curriculum recognizing the value of the changes to classroom teachers as well.

Figure 2: Mission Briefing



MISSION 1:

OCEAN RESCUE

GOAL: CREATE A ROBOT THAT CAN RESCUE A DISTRESSED SWIMMER

MISSION REQUIREMENTS:

Your team’s robot must move forward along the surface of the water from one end of the pool to the other, where it will change direction and move backward to the start.

MISSION CONSTRAINTS:

- ☐ Robots must float on the surface of the water
- ☐ Move forward and backward in a straight line
- ☐ Use only 1 motor
- ☐ Include as many small boat propellers as necessary
- ☐ Use any sensor for the controller except the buttons on the NXT device
- ☐ Program your robot using loops and switches
- ☐ Experiment with gears to change the robot’s speed
- ☐ Allow each teammate to

Robots are often created to perform tasks that humans cannot do because of environmental constraints. The marine environment can present harsh conditions for human survival, and consequently, their rescue. Imagine a distressed swimmer that is far from the beach and the lifeguard station. How might a robot help in this scenario?

In this mission, you will create a robot that can be driven along the surface of the water to a distressed swimmer. The swimmer can then grab ahold of the robot and be driven back to the shore where they will be taken care of by a lifeguard.

FYI

The robot in the picture above, named EMILY (Emergency Integrated Lifesaving lanYard), can rescue people up to six times faster than a human lifeguard. It can zoom along the water at 28 mph, and has a camera and speaker for easy communication between the lifeguard and the swimmer. For more information on EMILY, check out: http://students.egfi-k12.org/robot-soaks-up-the-sun-and-saves-lives-too/

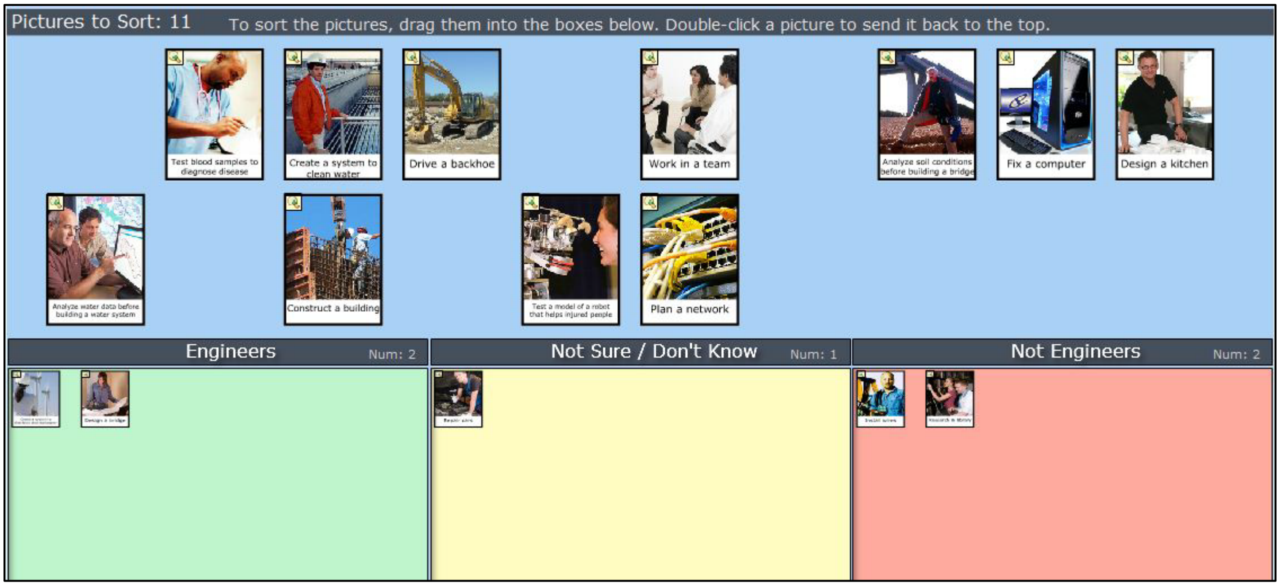
Use of Interactive Embedded Assessments

Anticipated Impact: Student Enjoyment, Learning; Fidelity of Teacher/Educator Implementation

Student learning gains in the physical science topics of gears/gear ratios, buoyancy/stability, and the Mindstorms programming language is measured through a series of pre- and post-assessments embedded within each of the four design challenges. Originally, student assessment data was obtained by administering a complete pre-test before the project and a complete post-test after but this method did not align well with the desirable atmosphere of a summer camp experience. Subsequently, the pre/post assessment regime was redesigned into a series of embedded assessments that gathers the same data from participants, but in more manageable “chunks” that were integrated with log entry activities. Smaller pre/post assessments are given before and after each of the four design challenges. The questions are the same, but since they are spread throughout the project, each assessment is brief and less intimidating. Furthermore, each post-assessment is combined with log entry activities that ask the participants for their opinions about how the challenge went, what roles they played, the effectiveness of their team, and what they have learned about engineers and engineering so far. The goal of this redesign is to impart to participants the feeling that they are evaluating the project rather than the other way around. One additional change was to add instant access to assessment results by teachers and educators so they can be used for formative assessment.

Furthermore, the assessment used to measure students’ awareness of engineering careers was transformed into an interactive online activity that could simultaneously be used to facilitate a rich discussion. This Flash-based application is called the “Pile Sort,” and it involves students accessing a virtual set of cards with pictures of people performing various activities, and then sorting them into three piles: Engineers, Not Engineers, and Not Sure/Don’t Know. The goal of the pile-sort activity was to evaluate if the participants’ understanding of who engineers are and what engineers do expanded from beginning to end of the project. After the activity, instructors can discuss with the students where they placed each card and why they did so. An example of the activity is shown in Figure 3.

Figure 3: Pile Sort Activity



Pictures to Sort: 11

To sort the pictures, drag them into the boxes below. Double-click a picture to send it back to the top.

Hands-On Science Learning Activities

Anticipated Impact: Student Learning

Where possible, core topics of the curriculum are introduced using interactive and hands-on activities. This is especially important for participants in informal learning environments since presenting formal lessons of the project's science concepts can detract from the fun and engaging atmosphere that is created purposefully. For example, rather than learn about gear ratios via a lecture or demonstration format, participants create "human gears" out of groups of people and physically walk through the gears' interactions.

A Stronger Focus on Utilizing Role Models & Teaching about Engineering Careers

Anticipated Impact: Student Learning & STEM Interest/Engagement

Using practicing engineers as role models who can discuss their personal experiences and motivations with youth is important for increasing awareness of and enthusiasm for engineering careers. Interactions can range from speaking to the group during a break, to sitting with a group of students and talking over lunch, to leading the class in a tour of the engineer's place of work, and to using videos of engineers talking about their work. In part as a result of seeing less change than hoped during the first year of implementation, during the second year of training, increased emphasis was put on having the teacher/educators inform students about engineering and engineering careers. As a result, more teachers had engineers visit or had field trips, while educators continue to do this. All of the teachers, with the exception of one who reported that STEM career teaching was already built into the school's curriculum, reported that they had included at least one activity to introduce engineering careers and about half included more than one. However, only the summer camps had engineering students as mentors or guests.

Our original expectation was that the informal educators would be less familiar with STEM concepts, including engineering design. This turned out not to be true, or not to be entirely true, because many of the informal educators were science and/or engineering classroom teachers or had prior experience as engineering professionals. There were not clear differences in the pre-tests between educators from the two environments. What turned out to be more important was the individual trainer's emphasis during training. Trainers who emphasized engineering had an impact on this area on both teachers and educators who then emphasized engineering.

Include More Videos

Anticipated Impact: Student Learning, STEM Interest/Engagement; Fidelity of Teacher/Educator Implementation

Although the curriculum is intended to be comprehensive, providing all of the science, engineering, and programming content necessary, it may be easier for some students to learn new concepts by watching actual demonstrations. This is especially true if the program instructor does not have a strong STEM background. Therefore, a variety of videos have been made for use as optional enhancements to the curriculum. Currently, there are six concept-related videos covering gears, buoyancy, stability, and backflow. There is also a video detailing how to repair and maintain water-damaged motors. Two of the most difficult concepts for students to understand in this project are buoyancy and stability. In addition to the videos, there is an interactive simulation for buoyancy that allows students to experiment with an object's size and weight to observe how its buoyancy is affected.

One of the underlying goals of the curriculum is for students to learn more about engineering careers, some of which pertain to underwater robotics (e.g., an oceanographic engineer who explores underwater habitats or a mechatronic engineer who designs robots that swim like fish). Videos that highlight a variety of engineering careers and compliment specific activities have been included as resources within the curriculum. For example, a career-matching activity requires students to match cards bearing the names of different engineering careers such as mechanical engineering and electrical engineering with cards that have the descriptions of those careers. The videos can also be used to demonstrate different aspects of the engineering design process such as brainstorming. In one activity, students watch a video in which engineers are engaged in brainstorming different ways to carry a laptop computer, and this serves as a model for them as they brainstorm designs for their underwater robots. Lastly, the videos can serve as a stand-in for introducing students to real engineers if none are available to meet with students.

Include Short, Individual Programming Exercises and Sample Programs

Anticipated Impact: Student Learning; Fidelity of Teacher/Educator Implementation

For the design challenges in this curriculum, students work with the visual, icon-based programming software that accompanies the LEGO® MINDSTORMS® kits. They create simple programs to control their robots. For teachers/educators and students who have never done programming before, this may seem to be an overwhelming task despite the detailed instructions and graphic images provided in the curriculum. In order to prepare and encourage students for developing more sophisticated programs for their robots they are first presented with short, simple programming exercises designed to be completed by all group members – not just a designated programmer. Additionally, sample programs are provided to participants in case they become truly stuck so as not to impede the development of their robots.

Offer a Culminating Showcase of Accomplishments

Anticipated Impact: Student Enjoyment & STEM Interest/Engagement

Many robotics projects are either based on or culminate in competitions and can be highly motivating and enjoyable for students. However, competitions can also be disappointing and frustrating for students whose robots may not perform well in a competition. It order to have more appeal to girls, it was decided that for this program a showcase culminating event would be used in lieu of a final competition since research studies have shown that girls thrive in more cooperative and less competitive environments. [13,14, 15,16] In the showcase event, participants display and describe the strengths of their robots as well as the areas for improvement, and then perform a demonstration of their robots accomplishing the mission objectives. Afterwards, other students are invited to provide compliments and constructive feedback. The showcase event serves to highlight participants' successes and may be more engaging to girls. Therefore, this curriculum offers showcases as an alternative to competitions for each of the design challenges. This removes the competitive nature of the culminating activity, relying instead on emphasizing the context to provide the motivation, and it encourages increased collaboration. For example, in the first mission, the context is that the students' robots would model a real-life robot that rescues people from drowning. As long as a robot can satisfy the mission challenge in an appropriate amount of time, students can feel they are successful. This approach offers objective criteria for success while removing the negative aspects of competitions.

Student Outcomes and Impact

As stated previously, the four hub sites studied in this paper joined the project at different times. During the project's second year, one formal site and one informal site were in their second year of implementation (Formal #2 and Informal #2) and one formal site and one informal site were in their first year of implementation (Formal #1 and Informal #1). It was during this second year of data collection that we had the first opportunity to examine and analyze data from all four sites. This paper examines student impact at the two formal and two informal sites during this time period. The two questions addressed are:

- Are student outcomes similar regardless of the teaching environment (formal vs. informal)? If they differ, what are the differences and what accounts for them?
- To what extent was the curriculum taught as designed (fidelity of implementation) and is greater fidelity associated with better student outcomes?

During the second year, implementation began in 41 classrooms or camps, with 36 completing at least three of the four challenges. A background survey was administered to all students/campers before embarking on the curriculum activities. In addition, each challenge had assessments embedded within it and there was a final survey at the end. The number of students/campers with complete data sets was 415.

It was originally assumed that the answer to the first question would be that student outcomes would be different--that content would be the focus of the formal classrooms so that these students would perform better on the content-related assessments than the campers, while engagement and engineering careers would be the focus in the summer camps so that these youth would show higher levels of engagement and interest in engineering. However, for a number of reasons, the results were more complicated.

Formal and Informal Environments: Differences and Similarities

First, there was great variation from classroom to classroom and camp to camp within each site as shown in Table 1, with the largest percentages at each site highlighted. The averages (or mean values) by site therefore hide large ranges within that site. Second, the sites were uneven in terms of total number of participants, with one site in each environment between two and four times as large as the other site in that environment.

This meant that the results for each environment were heavily weighted by the results for one of the sites within it. For example, it was assumed that the two informal sites would be almost entirely girls but Informal #2 was only 60 percent female and had almost four times as many participants, lowering the overall percent female in the informal environment to 63 percent—a similar gender profile to Formal #1 which was 62 percent female. Within the two formal sites, Formal #1 had almost three times as many participants as Formal #2 and weighted the gender profile for the formal environment despite the fact that Formal #2 was 91 percent male. As a result, when informal was compared to formal, gender was not a significant factor.

Table 1: Number of participants and gender by site

(Largest percentages at each site highlighted in green)

	Formal #2	Formal #1	Informal #2	Informal #1
Total participants	68	146	177	49
% of total	32%	68%	78%	22%
Male	91%	38%	40%	25%
Female	9%	62%	60%	75%

There were some similarities across all sites. Only 10 percent or less of the students at any site reported that school was “Hard” or “Very hard” and almost all at each site planned on some form of post-secondary education. STEM subjects were listed among the subjects liked most at all the sites and math and English Language Arts among the subjects liked least, and over 80 percent of the participants at all the sites agreed or strongly agreed that they liked science. Most of the participants at all the sites reported that they had studied forces and motion, but only a few at three of the four sites reported that they had studied buoyancy.

But there were also additional differences that make comparisons of the two environments problematic. The first was the different mix of grade levels at each site. Thus while Formal #2 had almost 50 percent of its participants in the last two years of high school, Informal #1 had over 50 percent of its participants in middle school. Informal #2 had over 75 percent in the first two years of high school while Formal #1 students were evenly spread across grade bands as shown in Table 2. In this table, the highest percentage for each site is highlighted in green.

Table 2: Grade level by site

(Highest percentages at each site highlighted in green)

	Formal #2 (n=68)	Formal #1 (n=146)	Informal #2 (n=177)	Informal #1 (n=49)
Middle school	43%	30%	10%	53%
Grade 9 & 10	9%	40%	76%	38%
Grade 11 & 12	48%	30%	14%	9%
	100%	100%	100%	100%

More Formal #2 students had taken pre-engineering or engineering courses, but more Informal #1 students had experience with robotics and programming. Also, when asked about science and engineering courses, majors, and careers, the Formal #1 students were much less enthusiastic about any of these than the Formal #2 students—and since there were more than twice as many of them, their responses weight the responses when the formal sites were taken together.

Student Enjoyment

If we return to the original hypotheses comparing the two environments, we find the following regarding student perceptions of enjoyment: The informal environment had higher student ratings for enjoyment than the formal environment, with 72 percent of the formal environment students giving an A (A+, A, A-) compared to 94 percent of the informal environment campers as shown in Table 3. The camper ratings were similar at the two informal sites while the student ratings were high at Formal #2 (and similar to the informal sites) but low at Formal #1.

Table 3: Student ratings for enjoyment

(Largest percentages at each site highlighted in green)

	Formal #2 (n=67)	Formal #1 (n=135)	Informal #2 (n=165)	Informal #1 (n=48)
A+	54%	33%	64%	56%
A	18%	19%	18%	17%
A-	9%	15%	7%	17%
B+	4%	12%	3%	2%
B	6%	8%	4%	4%
B-	0%	2%	3%	2%
C or less	8%	11%	1%	2%

Student Learning

However, we also found that the campers in the informal environment gave higher student ratings for learning, with 83 percent giving an A for learning, compared to 69 percent in the formal environment, as shown in Table 4 with the largest percentages at each site highlighted in green. Again, the camper ratings were consistent at the two sites but the student ratings were high at Formal #2 (and similar to the informal sites) but low at Formal #1.

Table 4: Student ratings for learning

(Largest percentages at each site highlighted in green)

	Formal #2 (n=67)	Formal #1 (n=135)	Informal #2 (n=165)	Informal #1 (n=48)
A+	43%	26%	42%	42%
A	18%	23%	28%	33%
A-	15%	17%	11%	15%
B+	10%	17%	7%	4%
B	4%	8%	10%	6%
B-	6%	5%	0%	0%
C or less	2%	4%	1%	0%

Students also completed content assessments which included questions on gears, buoyancy, and programming. There were matched pre- and post-assessments for challenges 1-3 for 441 students. If we return to the original hypotheses comparing the two environments, we find the following regarding student learning:

The increases on the three assessments (gears, buoyancy, and programming) were statistically significant at all four sites (p = .000).

However, despite what was in some cases great improvement, the final mean scores for each group were never over 70 percent and in most cases much lower. In Table 5, which looks at each test separately, the changes from pre- to post-test and the final mean scores are presented as percentages in order to make them comparable across assessments, with the highest percentage for each test highlighted in green.

Table 5: Change in Pre – Post Test Scores

(Highest percentage for each test highlighted in green)

	Gears		Buoyancy		Programming	
	Change Pre-Post	Mean as % of total possible score	Change Pre-Post	Mean as % of total possible score	Change Pre-Post	Mean as % of total possible score
Formal #2	2%	67%	7%	60%	10%	54%
Formal #1	43%	53%	1%	48%	2%	44%
Informal #2	58%	57%	13%	53%	17%	56%
Informal #1	24%	62%	1%	57%	18%	60%

The mean post-test scores for gears and buoyancy were equivalent for the formal and informal environments but the mean post-test scores for programming were higher in the informal environment. As with the ratings for enjoyment, the scores were similar at the two informal sites, but while Formal #2 had the highest mean post-test scores for gears and buoyancy, Formal #1's low scores brought down the overall scores of the formal sites.

However, when pre-test scores are taken into consideration, an ANCOVA shows that the environment is only a significant factor for programming ($p < .01$), predicting 30 percent of the variance in the post-test scores for this content area. Neither gender nor grade level explains the differences in the assessment scores when sites are compared. There were only six girls in the Formal #2 student population, so it was not possible to make comparisons by gender for this site. For the remaining three sites, gender was not a factor in either the pre-test or post-test scores when pre-test differences were taken into consideration. Grade level only explained the differences in the post-test scores at the Formal #1 site. This may be because at this site the students were more evenly dispersed across all grade levels than they were at the other sites.

The participants' self-report of their previous experience with the topic being assessed was correlated with these differences only at some sites and only for some assessments, suggesting that previous experience was not necessary.

In addition, Table 6 shows that teacher/educator knowledge of the topic, as measured by their post-test scores, was not correlated with student post-test scores for any topic except programming. There was a strong correlation for programming at all sites but Informal #2, suggesting that student success with programming may depend in part on teacher/educator preparation. Teacher content knowledge of buoyancy was strongly correlated with the buoyancy post-test scores only at one site and teacher content knowledge of gears was not correlated with student post-test scores at any site. In other words, teachers without some prior knowledge of programming were less likely to have their students do well on the programming assessment, but this was not the case for the other content areas. Here it may be important to note that Informal #2 was in its second round of implementations, while Formal #1 was in its first.

Table 6: Correlation between teacher post-test and student post-test scores by site

(Significant correlations are highlighted in green)

	Formal #2	Formal #1	Informal #2	Informal #1
Gears post-test	No	No	No	No
Buoyancy post-test	No	Yes r=.41 p = .000	No	No
Programming post-test	Yes r=.46 p = .001	Yes r=.23 p = .006	No	Yes r=.42 p = .002

Student Interest in Science and Engineering

The original hypothesis was that the camps, with more of an engineering focus, would be more likely to increase the participants' interest in science and engineering and their knowledge of engineering careers. Here the different number of participants at each site again weighted the results. When both sites in each environment are combined, a higher percentage of campers than students expressed an interest in pursuing science and engineering as shown in Table 7. In this case, the informal results are weighted by the better results at Informal #2 compared to Informal #1 and the formal results are heavily influenced by the poor results at Formal #1:

Table 7: Interest in Science and Engineering

	Formal	Informal
This project made me want to do more after school **science or engineering** projects if they are available.	45%	67%
This project changed my mind about how interesting **science** is.	54%	59%
This project made me want to take more classes in **science** if they are available.	38%	63%
This project changed my mind about how interesting **engineering** is.	55%	76%
This project made me want to take more classes in **engineering** if they are available.	44%	65%
This project made me consider **engineering** as a career path.	34%	55%

At all sites, the participants' grades for enjoyment and learning were highly correlated with their self-assessment as to how much the project had changed their minds about engineering, as shown in Table 8, suggesting that where the program was more engaging, and the participants thought they learned a lot, they were more likely to show interest in engineering as a subject and career path.

Table 8: Correlations between student grades for learning and enjoyment and interest in engineering

(Significant correlations are highlighted in green)

Formal #2 (n=67)	Pearson Correlation	Sig. (2-tailed)
Grade for learning	.347**	.004
Grade for enjoyment	.298*	.014

Formal #1 (n=135)	Pearson Correlation	Sig. (2-tailed)
Grade for learning	.217*	.011
Grade for enjoyment	.402**	.000

Informal #2 (n=165)	Pearson Correlation	Sig. (2-tailed)
Grade for learning	.358**	.000
Grade for enjoyment	.368**	.000

Informal #1 (n=48)	Pearson Correlation	Sig. (2-tailed)
Grade for learning	.178	.226
Grade for enjoyment	.393**	.006

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Finally, there was some indication that the informal sites taught students more about engineering careers than the formal sites. Thus Table 9 indicates that the ability of the participants to recognize who engineers were at the end of the implementation was equal for the formal and informal environments, but there were greater increases at the informal sites. The highest mean post-test score was at Formal #2, with the overall mean score brought down by Formal #1's lower scores, while the scores at the informal sites were similar to each other.

Table 9: Mean score for engineer cards
(Highest score = 9)

	Formal #2 (n=68)	Formal #1 (n=121)	Informal #2 (n=161)	Informal #1 (n=48)
Pre-test score	7.21 (SD=1.56)	5.98 (SD=2.09)	6.32 (SD=1.58)	6.19 (SD=1.93)
Post-test score	7.53 (SD=1.57)	6.47 (SD=2.11)	7.12 (SD=1.47)	7.00 (SD=1.77)
% increase	+4%	+8%	+13%	+13%

When pre-test scores for the engineer cards are used as a co-variate, ANCOVA shows that environment is a significant factor ($p < .05$), predicting 40 percent of the variance in the post-test scores.

Fidelity of implementation

For the second question addressed by the evaluation, it was hypothesized that higher levels of fidelity would be associated with better student outcomes. In other words, students of teachers and educators who adhered to the practices encouraged in the curriculum would have greater success as measured by the embedded assessments. Implementation practices included spending an adequate amount of time with the curriculum, using the supplementary materials (including videos and simulations), using the Mindstorms sample programs, and including several engineering-related activities. Because we wanted to look at the impact of these factors across all sites, the analysis below includes the assessments scores for the entire student population rather than grouping them by site.

Time spent on the curriculum was strongly correlated with the post-test mean scores in all three content areas as shown in Table 10. The camps, which were generally one week in length, were more likely to adhere to the recommended time frame, while the time frame for the classroom implementations differed considerably. Further, the classroom time was much more likely to be interrupted and the class size more likely to make larger teams necessary. Given the wide range in hours spent in the classrooms, this suggests that the constraints of a one-week camp dedicated to this curriculum made it more likely that the participants would spend the recommended number of hours.

Table 10: Correlation with time spent on project

(Significant correlations are highlighted in green)

Formal sites (n=191)	Pearson Correlation	Sig. (2-tailed)
Gears post-test scores	$.298^{**}$	.000
Buoyancy post-test scores	$.304^{**}$	.000
Programming post-test scores	$.374^{**}$	.000

** Correlation is significant at the 0.01 level (2-tailed).

For other aspects of fidelity, the picture that emerged was more complicated. Use of concept-related videos and simulations for gears, buoyancy and stability was not correlated with post-test scores on gears and buoyancy (*p*=.27, *p*=.56). The curriculum also includes sample Mindstorms programs for each of the first three challenges. Nine teachers and educators demonstrated the sample programs to their students, while seven teachers and educators allowed students to use the programs themselves. The teacher/educators demonstrating the sample programs was not correlated with the participants programming post-test scores (*p*=.45), while the participants' use of the sample programs was *negatively* correlated with their programming post-test scores (*p*=.02)--suggesting that this use may not have helped the participants learn programming because they did not have to work the programs out for themselves. Lastly, the number of engineering-related activities (e.g., visit to an engineering facility, watching engineering career videos) was not correlated with the participants' post-project pile sort scores (*p*=.82). This may have been because it was the time spent on these activities, and their quality, that was the important factor, rather than the number of activities.

Discussion and Next Steps

The formal and informal sites represented two very different environments. The formal was the standard classroom, with the project curriculum often implemented over an extended period of time with many interruptions, while the informal was a summer camp, generally confined to one week and combined with other engaging activities. The findings presented in this paper suggest that if students in both formal and informal environments enjoyed the curriculum, there was a strong possibility that they thought they learned. Contrary to the original hypothesis, students from the informal hub sites did better on content learning than students in formal classrooms. On the other hand, the informal sites did better on STEM interest and engagement, as hypothesized.

In previous projects using earlier versions of the curriculum, [17] teacher content knowledge and confidence in teaching the content area were shown to be significant factors in explaining the variance in student post-test scores. That was not the case in our recent analysis which indicated that teacher/educator knowledge of the topic was not correlated with student post-test scores for any topic except programming. This may be due to the expanded instructions, descriptions and images, and educator resources now available in the curriculum, especially in the informal educator version which has more step-by-step guided instructions and explanations.

Overall, the curriculum has worked best in the informal environments. This may be attributed to the amount of time spent on the curriculum during intensive summer camp experiences whereas there is a great range of class time devoted to the curriculum in the formal environment. Engagement was higher at the informal sites, they did more with engineers and engineering, and participants did better on the assessments. Because the hub sites are not comparable in terms of grade level and gender of participants, the analysis and concluding results become more complicated Since grade level is an important factor--older students do better--this makes the formal and informal look more alike than they are. Ultimately, we decided not to compare the formal and informal environments as originally planned but, instead, to look at those factors that are associated with success across all students.

As this five-year research project continues, we will continue to examine the differential impacts of the *WaterBotics*® curriculum on different student groups and in differing implementation scenarios that ultimately will yield valuable understanding about strategies to foster learning in STEM areas and student interest and engagement in the STEM workforce.

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