Robotics Camps, Clubs, and Competitions: Results from a U.S. Robotics Project

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Abstract. Funded by the U.S. National Science Foundation, the University of Nebraska-Lincoln has spent the last eight years developing and implementing a comprehensive educational robotics program for youth ages 9-14. The program is delivered in informal (out-of-school) learning environments through robotics camps, clubs, and competitions and has provided robotics experiences to over 5,000 youth and 400 educators. The goal of the project is to positively impact the youths' science, technology, engineering, and mathematics (STEM) knowledge and attitudes – and to foster an interest in STEM careers. This paper summarizes the project's evaluation and research results, focusing on the youth outcomes that have consistently emerged across the years. We also present survey results on youths' perceptions of the STEM skills they learned in relation to camp, school, their personal life, and society.

Keywords: educational robotics, research, STEM knowledge, STEM interest

1 Introduction

Educational robotics represents a powerful, engaging tool for youth learning because they can touch and directly manipulate the robots, resulting in hands-on, minds-on, self-directed learning. Our project is based on a theoretical framework derived from experiential learning, which is similar to problem-based learning in that students learn concepts and principles through authentic experiences and problems, typically in small groups, and with teachers as facilitators [1]. We also situate robotics within an integrated STEM framework, where youth must utilize science (inquiry), technology, engineering and mathematics skills to successfully complete the robotics activities.

Empirical support for educational robotics comes from research showing that robotics can increase learning in specific STEM concept areas [2], [3], [4]. Robotics also encourages student problem solving [5], [6] and promotes cooperative learning [7], [8]. Beyond the potential to influence youth learning, educational robotics is a unique technology platform for increasing student interest in STEM. Internationally, many countries are investing in STEM educational programs to compete in the global marketplace and to increase the number of youth pursuing STEM careers [9]. Studies show that robotics can generate a high degree of student interest and engagement in math and science careers [10], [11].

This paper examines how our robotics program -- delivered through informal learning environments as summer camps, academic year clubs, and robotics competitions -- supports middle school youth STEM learning and motivation. Results are provided for three overarching areas of inquiry:

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1. What is the impact of the robotics camps, clubs and competitions on middle school youth STEM knowledge, attitudes, and workplace skills?
2. What is the impact of the robotics experiences on youth career interests?
3. How do youth perceive the value of the individual STEM knowledge and skills gained during the robotics summer camps? How do the learning experiences compare to those they experience in school?

2 Description of the Robotics Camps, Clubs, and Competitions

At the heart of our robotics project is the curriculum, which consists of approximately 40 hours of instruction involving the building and programming of robots using the LEGO Mindstorms NXT robotics platform. The format of the activities involves a short introductory presentation by an informal educator followed by hands-on activities supported by structured worksheets. Participants typically work in same-sex pairs to complete the majority of robotics tasks, and small groups of three or four students are formed for more advanced challenges. Individual lessons typically take one to two hours to complete; however more complex experiences can last as long as four hours. Sample lessons cover such skills as writing a simple program to display text on the brick, programming the robot motors for movement and various turns, using loops in a program, navigation to avoid obstacles using touch and ultrasonic sensors, and programming the sound sensor and the light sensor to track a line. (A complete description of the curriculum can be found in [12]; samples of the curriculum are on line at http://www.gt21.org).

The camps and clubs utilize the same basic curriculum but educators are given the latitude to modify and adapt the instruction to meet the needs of their participants. The camps are delivered in the summer and typically last 40 hours (one week). The clubs, which usually meet during the academic year, vary considerably depending on the organizational sponsor (i.e. 4-H, after school). Some clubs meet the entire academic year, others only a couple of weeks. The longer time frame allows more in-depth exploration of individual topics, but individual sessions can be as long as a week apart, which causes more fragmented learning. Instructors often have to review and refocus youth before proceeding with the instruction. The club format is also more susceptible to having youth drop in and out or miss individual sessions.

The robotics competitions supported through the project are through the FIRST LEGO League, one of the largest educational robotics competitions with 16,000 teams competing internationally. The project began sponsoring competitions in 2010, and the events have grown each year. The event is organized around a real-life science-based issue, with middle school participants assembling robots based on the LEGO Mindstorms kit to perform a set of defined tasks to address this issue. They also prepare an issue-based research project. Data from coaches has shown that team preparation typically lasts around 40 hours. The FIRST LEGO League does not have an official curriculum or coach training, but instead provides a handbook for coaches and links to external resources. To help support coaches in preparing youth for the competition, we made the project curriculum available. However, only about 20% of coaches reported using the project resources.

3 Methodology

3.1 Participants

Across the eight years of the project, we collected six years of data from 1825 campers, three years of data from 458 competition participants, and two years from 126 club participants. Camp participants represented a U. S. sample from 23 states, with approximately 70% male, 30% female. Competition participants, on the other hand, were concentrated in the Midwest; gender split was again 70% male, 30% female. The club data primarily comes from Nebraska, but data was also collected from youth from seven states. In general, 67% were males; 33% female. Unlike the camps and competitions, the project has less control over club origination, organization, and research participation, and the numbers of club participants are considerably smaller than those for the other two formats.

3.2 Instrumentation

The instrumentation used in the camps and clubs each year was identical, with questions assessing STEM knowledge, attitudes, and workplace skills. STEM content knowledge was measured through a multiple-choice assessment covering mathematics (including fractions and ratios), computer programming (such as looping and conditional statements), engineering concepts and processes (such as gears and sensors), and engineering design. This instrument was modified over the years to be more application oriented and to rely less on factual recall. In addition, early versions of the instrument did not include questions on engineering design and science (inquiry). The instrument's Cronbach alpha reliability was consistently around .82.

The attitudinal instrument [13] contains 33 items that utilize a Likert format ranging from (1) strongly disagree to (5) strongly agree. There are multiple scales, including youth perceived value of mathematics, science, and robotics, as well as their self-efficacy in performing robotics tasks. It also contains workplace skills questions focusing on youth use of teamwork (e.g. "I like being part of a team that is trying to solve a problem") and problem solving skills (e.g. "I make a plan before I start to solve a problem"). Unlike the cognitive instrument described above, this instrument was used consistently throughout the project, and showed high reliability as evidenced by a Cronbach alpha of .97. The final series of questions asked youth how interested they were in certain STEM-related careers. This section again used a Likert format ranging from 1 = very uninterested to 5 = very interested.

The competition instrumentation was similar to the one used in the camps and clubs, but was shortened because of the time constraints within a competition environment. Even with the fewer number of questions, however, the reliability was high, showing alphas of .80 for the knowledge test and .92 for the attitudinal survey.

Because our project was designed as an integrative STEM experience, we were interested in knowing how youth perceived the individual science, technology, engineering and mathematics content. Did youth view the camp primarily as a technology-oriented experience? Did they recognize that science and mathematics content was embedded within the curriculum? Did they believe what they learned in the summer camp would transfer into the school environment? To answer these questions, we developed nine generic Likert-type questions (5-point scale) that could apply to each of the four STEM disciplines. For example, one question involved youth use of the separate skills to successfully complete the robotics activities, i.e. "I had to use _________ skills to successfully complete the robotics skills in this camp." The question appeared four times on the survey, with a different STEM area appearing in the blank. Other questions probed youth perceptions of a) the individual science, technology, engineering, and mathematics skills they learned during their robotics experiences, b) how this learning differed from what they experience in school, and c) how it helped them understand the impact of STEM on their personal life and the world.

3.3 Data Analysis, Collection and Procedures

The basic research design used throughout the project was a repeated measures, pre-post design, with dependent "t" tests examining differences between means at the two time points. The results addressing research question 3 were analyzed through a series of one-way, repeated measures ANOVAs to ascertain specific differences between each STEM discipline in terms of youth perception of their impact at various levels – in the robotics camp, school, their personal life, and society.

Separate analyses of the research data were conducted for each year of the camps, clubs, and competitions and many of these annual results have been published elsewhere. This paper provides a synthesis of the research results, identifying data trends, and which reflect consistent and stable effects of the robotics experiences.

4 Results

Table 1 shows Cohen's d effect sizes for the various youth outcomes by format by year. Discussion of the results is organized around the three guiding questions.

1. *What is the impact of the camps, clubs and competitions on middle school youth STEM knowledge, attitudes, and workplace skills?*

While the camp results are the most stable, results from all three formats reveal comparatively high effect sizes for the knowledge outcomes. (Cohen's rules of thumb for interpreting effect sizes: a "small" effect size is .20, a "medium" effect size is .50, and a "large" effect size is .80). Closer analyses of the individual scale scores show that the results were driven primarily by increases in knowledge of engineering and programming. Camps also resulted in the most consistent attitudinal results, with highest effect sizes for robotics self-efficacy. Self-efficacy also showed consistent increases in clubs. However, results for the youth perceived value and importance of STEM subject areas (task value) did *not* show consistent increases. The competitions and clubs had low effect sizes and the camps did not begin to show impacts until the last two years of data collection. An ongoing problem was the fact that the pre-test scores have been relatively high (over 4.0 on a five-point scale), making it difficult to realize increases. The possibility for increase is particularly problematic for the robotics scale, where youth tended to have even higher pre scores than other areas.

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Table 1. Effects sizes for robotics camp, club, and competition research

	Camp					Club		Competition		
Outcome	'09	'10	'11	'12	'13	11-12	12-13	'10	'11	'12
Cognitive: Overall	.60	.72	.51	—*	—	.58	.69	.28	.06	—
Programming	.40	.70	.45	.43	—	.50	.96	.40	.09	—
Engineering	.44	.60	.62	.49	.43	.39	.59	.14	.09	—
Math	.49	.12	.05	.28	—	.01	.06	—	—	—
Eng. Design	—	—	—	.16	.17	.34	.16	—	—	—
Science	—	—	—	—	.11	—	.25	—	—	—
Task Value										
Science	.15	.10	.20	.14	—	.01	-.09	.20	-.02	.13
Math	.02	.03	.14	.30	—	-.08	-.08	.17	.06	.17
Robotics	-.11	-.06	.16	.38	—	-.05	-.05	-.02	-.11	.12
Robotics Self-efficacy	.57	.33	.37	.40	—	.04	.36	.22	-.02	.18
Workplace										
Teamwork	-.47	.03	.13	.05	—	-.02	-.02	.00	.11	.38
Problem Approach	.12	.31	.25	.19	—	-.04	-.04	.30	.17	.43
Career										
Scientist	.05	.04	.14	.08	.16	.05	-.20	-.06	-.02	.08
Engineer	.11	.13	.20	.01	.09	.08	-.25	-.08	.16	.21
Mathematician	-.08	.18	.13	.08	.17	.10	-.16	.06	.15	.11
Technologist	.09	.01	.11	-.01	.13	-.07	-.41	-.02	-.19	.07

*Data not available

The problem approach scale from the workplace skills instrument also showed increases for all three formats. In contrast, teamwork, which was emphasized in all formats and was particularly important in the robotics competitions, had low effect sizes, including several that were negative (representing pre-post decreases).

2. *What is the impact of the robotics experiences on youth career interests?*

The camp data is again more positive, particularly for engineering. In addition, there were increases in youth interest in engineering careers in two of the three years of competition data, but not in science, technology, or mathematics. The clubs did not show any increases in youth interest in pursuing STEM careers.

3. *How do student perceive the value of the individual STEM knowledge and skills gained during the robotics summer camps? How do the learning experiences compare to those they experience in school?*

Results are presented in graph form below. The means above the scale midpoint (3) in Figure 1 show that youth perceived that the STEM skills they learned during the camp helped them to be successful in completing the robotics activities and in understanding how STEM impacts society and their personal life. (Average SD = 1.09.) They also reported that they used technology and engineering skills more than science and mathematics, and they gained significantly more science, engineering, and technology knowledge than math to help them in school and in their personal life.

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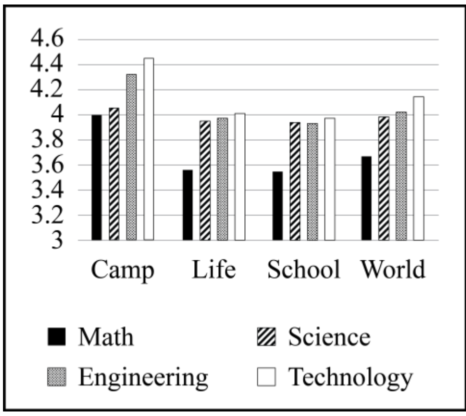
However, even though the math skills were considered less useful, youth still rated the math knowledge gained as being helpful (3.56 to 4.00 on a 5-point scale).



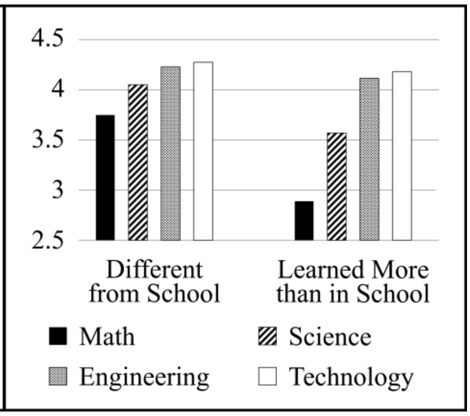


Fig. 1. Impacts of STEM skills learned in robotics camps

Fig. 2. STEM learning from camps vs. school

Results shown in Fig. 2 show that youth generally felt that all the STEM skills they learned were different from school (3.75 to 4.28 on a 5-point scale; average SD = 1.08) and particularly the technology and engineering skills. Fig. 2 also shows dramatic differences between the four disciplines in terms of whether youth perceived that they learned more in the camp than in school. Engineering and technology were again rated significantly higher, with math having the lowest rating (average SD = 1.20). Looking at the data descriptively, there is one result which did not exceed the scale mid-point. Youth did not believe that they learned more math in camp than in school (M = 2.92 on 5-point scale).

One question directly asked youth to assess their level of learning of each of the four STEM areas (1=none, 2=a little, 3=some, and 4=a lot). Again, youth believed that they learned significantly more science (M=3.39), technology (M=3.52), and engineering (M=3.45) than math (M=2.72).

In comparing the out-of-school learning environment to the in-school environment, youth also reported that the camp learning was more interesting (M = 4.2 on 5-point scale) and involved more hands-on activities (M = 4.36).

5 Discussion

Results show that robotics summer camps, academic year clubs, and competitions promote STEM learning, particularly in terms of knowledge of engineering, engineering design, and programming. The higher scores for engineering and programming may reflect the lack of an engineering course in middle school and the unique technology skills required to program a LEGO robot. With no previous exposure to this specific content, it is not surprising that youth showed significant gains in knowledge in these two areas. Mathematics knowledge, on the other hand,

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did not show increases from participation in robotics clubs and competitions and limited increases in the camps. The student perception data also triangulates these results; youth reported learning about engineering and technology but they did not believe they learned a lot of mathematics from camp participation.

Consistent results were found for youth robotics self-efficacy, suggesting that participation in robotics camps, clubs, and competitions increases student self-confidence in performing robotics tasks. The self-efficacy results, which focused on student robotics *performance*, complement those from the knowledge assessment, which assessed basic knowledge. The self-efficacy increases reflect youth growing in self-efficacy as they gain experience in writing programs to effectively control their robot's actions.

A major goal of the robotics project was to increase student perceptions of the value and importance of science, technology, engineering and mathematics, with the hope that such attitudinal increases would translate into further STEM course taking and career interest. Our data has shown that most students enter the program with relatively high expressed interest, leaving little room for increases. We did, however, begin to see some camp impacts during the last two years of data collection. The positive results in the later years of the project may be due to the fact that the camp format and curriculum were constantly being refined as we gained experience, and these results may reflect project formative improvement.

The careers data showed most success in increasing interest in engineering careers. We expect that the engineering increases are due the fact that youth are typically not exposed to any engineering curriculum in middle school and are unfamiliar with engineering both as a field of study and as a career. Thus, their experience with robotics design and the engineering process, coupled with explicit discussion of the responsibilities of an engineer as part of the curriculum, may have fostered both an increase in the knowledge of engineering, as well as in career interest. Interest in engineering careers also increased in two of the three years of competition data, but not in science, technology, or mathematics. Since there was no specific competition curriculum and no coach training, coaches focused on the requirements of the competition itself, with limited emphasis on educating youth about STEM careers. The lack of any significant results for the clubs may also be due to the variation in club format, with leaders having the option of picking and choosing the lessons. Thus, it is entirely possible that leaders omitted the lessons dealing with STEM careers in order to focus more on the hands-on robotics activities.

Regarding the workplace skills, consistent results were found for problem solving, which we believe is a result of the extensive troubleshooting necessary to control a robot. Informal observations showed that youth moved from using ineffective problem solving approaches, including trial and error, to a more plan oriented approach. Results across all three formats support the use of robotics as an excellent vehicle to promote more systematic problem solving in middle school youth

In contrast, the lack of consistent increases in the teamwork scale may be due to the complex influences of peer relationships in middle school years and the variation in facilitator expertise in encouraging teamwork. More complete results of the camp teamwork results, including gender analyses, can be found in [12].

Finally, we know that the learning environment can shape the participant's experience and impacts, and our research showed that robotics summer camps, with their structured one-week format, resulted in the most potent impacts. However, the club format, despite its inconsistent length and youth participation, also showed positive increases in learning And despite the fact that increasing STEM learning is not an articulated goal of robotics competitions, our research showed positive learning impacts, as well as general attitude changes. Overall, the research results highlighted that despite the differences in goals, format, and curriculum, camps, competitions and clubs can all contribute to youth STEM learning and more positive STEM attitudes. Our research echoes other findings [14] showing that multiple formats can result in successful robotics programs, with positive impacts on youth.

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