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Impacts of After-School Robotics Programming on STEM Interests and Attitudes

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Abstract
Despite the growing numbers of after-school STEM programs, relatively little research on STEM education has focused on the role that after-school and out-of-school programs can play to reinforce STEM learning and help engage young people in educational pathways leading to STEM careers. This paper presents interim findings from a multi-year longitudinal impact study aimed at assessing the effectiveness of one group of after-school STEM programs – after-school robotics competitions – in increasing STEM interest and attitudes and encouraging students to pursue STEM-related education and career trajectories. The study is tracking over 1200 students (822 *FIRST* participants and 451 comparison students) involved in in three national after-school robotics programs operated by *FIRST*, a national nonprofit that operates after-school robotics competitions for young people ages 6-18. Data sources include baseline, post-program and annual follow-up surveys of participants and comparison students, supplemented by baseline surveys of parents and team leaders and interviews and focus groups with team members and comparison group students. At 48 months after program entry, program participants show consistent, statistically significant positive impacts on a core set of STEM-related attitudinal measures: interest in STEM, involvement in STEM-related activities, interest in STEM careers, STEM identity, and STEM knowledge. Positive impacts are evident for program participants as a whole and for key subgroups including women, low income and minority students, with particularly strong impacts for female participants.

Introduction

Over the past two decades, educators and policy makers have expressed growing concerns over the levels of math and science achievement among American students and the gradual decline in the numbers of young people moving into science, technology, engineering, and math (STEM) careers (Campbell, Jolly et al. 2002; TAP Campaign 2005; Committee on Prospering in the Global Economy of the 21st Century 2006; National Science Board 2012). These concerns have led to the development of new standards for science and technology education (National Committee on Science Education Standards and Assessment 1996; International Technology Education Association 2000; National Research Council 2012), new policy initiatives aimed at promoting science and technology education (U.S. Department of Education 2006; America Competes Act 2007; White House Office of Science and Technology Policy 2013), and a growing body of research on math and science learning and the pathways leading to STEM-related careers (Jacobs 2005; Cannady et al. 2014).[1] While some have challenged the picture of looming shortages of scientists and engineers and recent studies have indicated that American students are taking more science and advanced science courses in high school (Lowell 2007; Dalton 2007; National Science Board 2012), concerns persist that in an increasingly knowledge-driven global economy, the United States needs to expand the pipeline into STEM-related careers (National Science Board 2006;U.S. Congress Joint Economic Committee 2012).

While the interest in expanding the numbers of young people moving into science and technology fields has grown, a relatively small proportion of the research on STEM education has focused on the role that after-school and out-of-school programs can play to reinforce STEM learning and help engage young people in educational pathways leading to STEM careers. Though there are scattered studies of individual after-school programs and summer science enrichment efforts (Fancsali 2002; Gibson and Chase 2002; Chacon and Soto-Johnson 2003; Markowitz 2004; Weinberg *et al* 2007; Barker and Ansorge, 2007; Welch 2010; Barnett et al 2011), most of the existing studies focus on shorter-term outcomes and/or are based on self-reported impacts, and few incorporate a control or comparison group design (Whitehurst 2004, National Research Council 2015). Given the growing emphasis on after-school programming in education and in promoting more hands-on learning experiences in science and technology-related fields, it is becoming increasingly important to better understand the role that after-school science and technology programs can play in moving young people toward STEM-related careers.

FIRST®

This paper presents interim findings from a multi-year longitudinal impact study aimed at assessing the effectiveness of one group of after-school STEM programs – after-school robotics competitions – in increasing STEM interest and attitudes and encouraging students to pursue STEM-related education and career trajectories. The study focuses on students involved in three of the four robotics programs operated by *FIRST*, a nonprofit that provides hands-on STEM learning challenges for students in grades K-12. The three competitive programs –*FIRST®* LEGO® League (grades 4-8), *FIRST®* Tech Challenge (grades 7-12) and *FIRST®* Robotics Competition (grades 9-12) – are among the world's largest robotics programs, engaging over 430,000 middle and high school-aged youth worldwide in annual robotics competitions aimed at strengthening their interest in science and technology while building teamwork, project management, communications, and other life skills. While differing in their specific designs and target age groups, all three programs are built on a common model: In each, teams of school-aged

[1] The website for the University of Michigan's Gender & Achievement Research Program also provides an extensive bibliography of math and science achievement articles at http://www.rcgd.isr.umich.edu/garp/.

youth work together under the guidance of two or more adults (an adult team leader plus technical mentors and other volunteers) to design and build robots that compete with other teams in completing a set of prescribed tasks.[2]

The primary goal of all three programs is to promote increased interest in science and technology and inspire innovation through hands-on engagement in designing, building, and competing the robots, with the ultimate goal of moving participants towards STEM-related education and careers. However, all three programs also place a heavy emphasis on the involvement of adult leaders and mentors from the community, the development of teamwork skills and team spirit, and the demonstration of values of "*Gracious Professionalism®*" and " *Coopertition®*" (the ability to both work with and compete against the same individuals and teams) in working both within the team and with competitor teams at the competition events. As such, the programs are designed to promote both interest in STEM and a broader set of 21st century life and workplace skills and values, including critical thinking, problem-solving, teamwork, communications, and project planning and management.

Background

The central hypothesis for the study is that involvement in organized after-school STEM programs like *FIRST* positively influences participants' education and STEM-related attitudes, leading to increased involvement in STEM-related courses and activities in high school and involvement in STEM-related studies and career plans in college. Three major questions guide the study:

- **What are the short and longer-term impacts of the *FIRST* LEGO League, *FIRST* Tech Challenge, and *FIRST* Robotics Competition programs on program participants?** Specifically, what are the program impacts on outcomes that include: interest in STEM and STEM-related careers, college-going and completion, pursuit of STEM-related college majors and careers, and development of 21st century personal and workplace-related skills?

- **What is the relationship between program experience and impact?** To what extent are differences in program experience – such as time in the program, role on the team, quality of the program experience – associated with differences in program outcomes?

- **To what extent are there differences in experiences and impacts among key subpopulations of *FIRST* participants?** In particular, are there differences in impacts by race, gender, family income or among those from urban, rural and suburban communities?

In considering these questions, the study draws on a broad body of research in educational motivation and youth development. Over the past two decades there has been a growing body of literature on motivation, and on science and math learning that draws on Jacquelynne Eccles' "Expectancy-Value" theory of achievement motivation. That developmental theory argues that "individuals' choice, persistence, and performance can be explained by their beliefs about how well they will do on the activity and the extent to which they value the activity" (Wigfield and Eccles 2000). Studies using that model have found that students' beliefs about their math and science competency, their expectations of success, and their valuing of math and science can predict grades and course enrollments in middle and high school, with a higher expectancy of success and valuing of math and science courses associated

[2] While the focus of this paper is on after-school programs, *FIRST* teams can be school-based or community-based, and meet regularly before, during, or after school.

with higher grades and enrollment in a more challenging math and science curriculum (Crombie, Sinclair et al 2005, Wigfield 1994, Wigfield and Eccles 2000, Simpkins et al 2006).

Eccles and her associates have also found that students' assessment of the "task value" of an activity, including its utility and inherent interest, are critical predictors of future activity, including enrollment in higher level math and science classes (Updegraff and Eccles 1996, Eccles 2007). Studies have found that involvement in both organized and informal math and science activities outside of school can positively influence students' attitudes and subsequent academic achievement and course enrollments (Jacobs et al 1998, Simpkins et al 2006). Studies of summer and other types of science and math enrichment programs, primarily for older students, have also reported impacts on participants' self-concept, interests, and ultimately choice of potential career (Gibson and Chase 2002), Markowitz 2004). The Social Cognitive Career Theory developed by Lent, Brown and Hackett suggests that these kinds of learning experiences can influence the sense of self-efficacy, outcomes expectations, interests and goals that inform the career choices that young people make (Lent, Brown and Hackett 1994). Maltese and Tai argue that hands-on learning, where students are able to "actively investigate the world around them" helps highlight the relevance of science and mathematics, leading to increased interest and persistence in STEM education (2011). In that regard, a central focus of the study (and this paper) is the impact of program participation on participants' STEM-related interests, identity, and understanding of the relevance of STEM to everyday life and careers.

Other theories of achievement motivation and success in the math and science "pipeline" suggest additional links between participation in afterschool robotics programs and school success, which may be considered a prerequisite for STEM-related careers. James Connell and his associates have argued that educational settings that provide students with opportunities for competence, autonomy, and relatedness (i.e., involved adults and families) help build a sense of competence and control and promote increased engagement in school. Those attitudes, in turn, have been found to be positively associated with persistence in school and improved school achievement (Connell 1994, Institute for Research and Reform in Education 1998, Skinner, Welborn, et al 1990). While less directly linked to achievement in STEM education, the study includes these measures to provide a means of assessing the impact of involvement in after-school robotics programs on a broader set of educational attitudes that are also related to long-term achievement and success in school.

The youth development literature also points to positive impacts from these types of hands-on learning experiences on a variety of life and workplace-related skills, including teamwork, communications, project management and problem-solving skills (Larson, Jarrett, et al 2004, Larson and Walker, 2006), skills that are also seen as important within *FIRST*. These types of skills are increasingly considered essential workplace skills and the teaching of these skills is now considered an integral part of engineering education (Partnership for 21st Century Skills 2008, North Central Regional Educational Laboratory 2003, ABET 2015, National Committee on Science Education Standards and Assessment 2012).

While math and science-related attitudes and those related to educational competence and engagement provide an interim set of outcomes or predictors of interest, this study also includes more direct measures of STEM-related *behaviors*. Involvement in higher level math and science courses in high school, for example, has been seen as an important predictor of who will engage in math and science-related occupations and careers (Updegraff and Eccles 1996). As enrollment in higher level high school math and science courses has increased in recent years generally, overall enrollment levels are still relatively low and there are significant enrollment gaps between different populations (Dalton

2007). As such, for those students who entered this study in middle school and stay through high school, enrollment in math and science courses (particularly upper level math and science courses) in high school will be one of the critical outcomes examined in the study.

The other major educational outcomes of interest are enrollment in STEM-related courses and majors in college. An earlier study of the *FIRST* Robotics Competition by Melchior *et al* found that program alumni were significantly more likely to major in science and technology and engineering fields, and to expect to go on to STEM careers, than a comparison group of students with similar backgrounds in high school math and science (Melchior et al 2005). At the same time, an analysis by the National Center for Educational Statistics found that 48% of Bachelor's degree students and 69% of Associate's degree students who entered STEM majors left those majors before completing college (Chen 2013). As such, a major goal of the longitudinal study is to track college outcomes including STEM-related course-taking, selection of STEM-related college majors, and persistence in those majors.

There is substantial literature on the issues of gender and race in math, science, and engineering, highlighting the concerns that women and minorities are less likely to major in engineering and technology fields or pursue occupations in those areas (Catsambis 1994, Crombie, Sinclair et al 2005, Eccles 1994, National Science Board 2006, U.S. Congress Joint Economic Committee 2012, U.S. Department of Education 2012). As noted earlier, some studies also suggest that part of the solution lies in providing young women in particular with more hands-on math and science experiences (Lee and Burkam 1996, Updegraff and Eccles 1995), and experiences that highlight the social utility of engineering (Eccles 2007). One of the questions this study examines is whether robotics competitions are effective in keeping young women in the STEM "pipeline" and can serve as a model for increasing STEM involvement for young women and other underserved populations.

Lastly, the research on achievement motivation and educational success is clear that family background and attitudes play a key role in guiding students' attitudes and choices. In the Expectancy-Value Model, these "influencers" represent critical contextual factors (Bleeker and Jacobs 2004, Dabney et al 2013, Jacobs and Bleeker 2004, Simpkins and Davis-Kean, et al 2005). As such, the study design included collecting baseline information from parents on family context, including parental education and support for STEM in order to be able to examine and control for those variables in the analysis.

Longitudinal Study Design

In 2011, *FIRST* contracted with the Center for Youth and Communities at Brandeis University's Heller School for Social Policy and Management to conduct a multi-year longitudinal study of *FIRST*'s middle and high school programs. The goal of the study, building on more than a decade of prior short-term evaluation studies was to document the longer-term impacts of *FIRST*'s after school robotics programs on participating youth and to do so through a design that meets the standards for rigorous, scientifically based evaluation research.

To accomplish that goal, the *FIRST* Longitudinal Study is tracking 1,273 students (822 *FIRST* participants and 451 comparison students) over five or more years beginning with entry of the *FIRST* participants into the program. *FIRST* participants were recruited to the study from a nationally representative sample of over 200 experienced teams in 10 states from the *FIRST* LEGO League, *FIRST* Tech Challenge, and *FIRST* Robotics Competition. New *FIRST* team members with no prior program experience were then recruited to the study by team leaders. Comparison group students were recruited from math and science classes in the same schools and organizations where the *FIRST* teams were located. Participant recruitment took place in two waves, with recruitment of initial group of students in Fall 2012 and recruitment of additional participants in Fall 2013 to increase the size of the overall sample for the study.

Data Collection

Once recruited into the study, team members and comparison students were surveyed at baseline and post-program in their first year, with annual follow-up surveys each spring thereafter. A baseline survey of parents provided additional background information on the family context for team members and comparison students, and Team Leader surveys at the end of the first year of team involvement in the study provided additional contextual data on the *FIRST* teams. Annual surveys have also been supplemented by interviews and focus groups with team members and comparison group students. The initial baseline surveys were administered in Fall 2012 (Wave 1) and Fall 2013 (Wave 2), with annual follow-up surveys each spring thereafter.

As of the Spring 2017 surveys, complete data have been collected through 48 months of follow-up (baseline, post-program, and three annual follow-up surveys). As Exhibit 1 shows, the response rate has been positive: overall 80% of study participants have continued through 48 months, including 74% of program participants and 90% of comparison students.

Exhibit 1: Response Rates Through 48 Months

	Baseline	**12 Month Follow-Up (Post-Program)**		**24 Month Follow-Up**		**36 Month Follow-Up**		**48 Month Follow-Up**	
	N	**N**	**% of base**	**N**	**% of base**	**N**	**% of base**	**N**	**% of base**
Wave 1 FIRST	488	386	79.1%	400	82.0%	371	76.0%	367	75.2%
Wave 2 FIRST	334	291	87.1%	265	79.3%	265	79.3%	244	73.1%
Wave 1 Comparison	177	NA	NA	157	88.7%	161	91.0%	162	91.5%
Wave 2 Comparison	274	259	94.5%	254	92.7%	248	90.5%	244	89.1%
Total FIRST	*822*	*677*	*82.4%*	*665*	*80.9%*	*636*	*77.4%*	*611*	*74.3%*
Total Comparison	*451*	*259*	*57.4%**	*411*	*91.1%*	*409*	*90.7%*	*406*	*90.0%*
Total	**1273**	**936**	**73.5%**	**1076**	**84.5%**	**1045**	**82.1%**	**1017**	79.9%

NOTE: Because the recruitment of Wave 1 comparison students extended until early 2013, the decision was made to not administer Post-Program surveys to Wave 1 comparison students in Spring 2013 and to wait until the next round of surveys (Spring 2014) to conduct a follow-up with that group. Wave 1 comparison students have been included in all subsequent data collections.

Outcome Measures

The major focus of the study is on the impact of program participation on STEM-related interests, attitudes, and behaviors. Key outcomes, developed in collaboration with staff at *FIRST* and with program and technical advisory groups during the planning phase of the study, include a combination of interest and attitudinal measures (for example, increased interest in STEM and STEM-related careers, sense of educational efficacy, and postsecondary aspirations); measures of self-reported life and workplace skills; and behavioral measures such as increased STEM-related course-taking in high school, postsecondary STEM course-taking, selection of college majors, and involvement in STEM-related activities in college. Exhibit 2 provides an overview of the key outcome measures for the study.

Exhibit 2: Key Outcome Measures

STEM-Related Interest and Attitude Scales	Personal Development and Workplace-Related Scales	Behavioral Measures
• STEM Interest (Level of interest in science, technology, engineering and mathematics) • STEM Activity (involvement in non-school STEM activities) • STEM Careers (interest in STEM-related careers, such as scientist, engineer, computer specialist, etc.) • STEM Identity (extent to which students see themselves as science, math or technology people) • STEM Knowledge/ Understanding (awareness of applications of STEM in real world, interest in learning more about STEM).	• Academic self-concept (students' sense of their educational competence/ commitment to learning) • College Support (adult support for college readiness/knowledge) • Self-Efficacy/Prosocial Values (self-confidence, sense of belonging and contribution) • 21st Century Skills (Self-assessed life and workplace skills, includes teamwork, problem-solving and communications subscales)	• STEM Course-Taking (High School) • Interest in STEM Majors in College/Declared Majors • STEM-Related College Course-taking • Involvement in College STEM-Activities (Clubs, competitions, internships, summer jobs) • STEM-related College Grants and Scholarships

The focus of this paper is on the STEM-related interest and attitude scales which provide indicators of the degree to which students express an interest in STEM, identify themselves as "STEM people," engage in informal STEM-related activities, are interested in STEM-related careers, and understand the role of STEM in the real world. The survey items were drawn from a mix of existing national surveys (for example, the U.S. Department of Education's National High School Longitudinal Study of 2009), questions that had been used in previous evaluation studies, and items developed specifically for this study. The specific items and reliability measure for each scale are included in the Appendix.

Sample Characteristics

As noted above, 1273 students agreed to participate in the study. Participants and comparison students were relatively well-matched at baseline in terms of basic demographic characteristics and academic background (Exhibit 3). Comparison group members were more likely to be female and in middle school grades at entry into the study, though the average age for participants and comparison group members were similar. Participants and comparison students included comparable proportions of African-American and Hispanic students, though a much higher percentage of program participants were Asian. The two groups had no significant differences in terms of community type and family income. In terms academic background and non-STEM related attitudes at baseline, the two groups were also very similar: participants and comparison students reported similar academic backgrounds and aspirations, and there were no significant differences in baseline measures of academic self-concept, support for college-going, self-efficacy and workplace-related skills. There were, however, significant differences at baseline in initial interest and involvement in STEM. The parents of *FIRST* participants were more likely to be involved in STEM-related careers and report that they supported involvement in STEM for their children. Program participants also scored significantly higher on baseline measures of STEM-related attitudes. As discussed below, these baseline differences were taken into account in the analysis.

Exhibit 3: Participant and Comparison Group Characteristics at Baseline

Measure	***FIRST***	**COMPARISON**	**ALL**
Gender*			
Male	67.8%	41.5%	58.5%
Female	32.2%	58.5%	41.5%
Average Age	13.96	14.14	14.02
School Level*			
5^{th}-8^{th} Grade	28.5%	41.5%	33.1%
9^{th} – 12^{th} Grade	66.7%	56.8%	63.2%
Other	4.8%	1.8%	3.8%
Race/Ethnicity*			
Asian	17.9%	10.2%	15.2%
Black/African-American	8.5%	6.6%	7.8%
White	67.8%	82.9%	73.0%
Ethnicity (NS)			
Hispanic	16.0%	10.0%	14.5%
Other Demographic Characteristics			
ESL (English as first language)*	79.3%	85.5%	81.5%
US Born (NS)	90.3%	93.0%	91.3%
Special Education (NS)	8.1%	3.3%	7.3%
Geography (NS)			
Urban	26.0%	23.2%	25.0%
Suburban	51.3%	53.0%	51.9%
Rural	22.7%	23.9%	23.1%
School Type*			
Regular Public School	71.3%	75.1%	72.6%
Charter School	3.7%	.5%	2.6%
Magnet School	15.3%	7.3%	12.5%
Private School	7.4%	15.6%	10.3%
Academic Performance - Grades (NS)			
Mostly A's	49.5%	49.4%	49.5%
A's and B's	34.0%	36.4%	34.9%
Student's Educational Aspirations (NS)			
BA Degree or More	95.2%	96.4%	95.7%
Parent's Education (Highest Degree) (NS)			
BA Degree or More	59.4%	58.6%	59.1%
Family Income (NS)			
Under $50,000	26.9%	21.7%	25.2%
$50,000- $100,000	32.5%	34.8%	33.2%
$100,000 and over	40.5%	43.5%	41.6%
Parent Employment/Experience in STEM*			
At least 1 Parent ever employed as engineer, scientist, programmer or other STEM field.	49.3%	40.8%	46.3%
Parent Support for STEM*			
Importance of having child participate in STEM activities (Important/Very Important)*	91.5%	75.4%	86.0%
Parent Encouragement of STEM (5 pt. scale)*	4.2	3.9	4.1
Parent encouragement of STEM careers (7 pt. scale)*	5.4	4.7	5.2

Measure	*FIRST*	COMPARISON	ALL
Survey Scales(average baseline scale score)			
STEM Interest*	4.1	3.7	
STEM Activity*	3.4	3.1	
STEM Careers*	4.5	3.7	
STEM Identity*	3.1	2.9	
STEM Knowledge*	5.6	4.9	
Academic Self-Concept	5.71	5.71	
College Support	2.18	2.21	
Self-Efficacy/Prosocial	5.5	5.5	
21st Century Skills	3.1	3.2	
Teamwork/Collaboration subscale	3.3	3.4	
Problem-solving subscale	3.1	3.1	
Communications subscale	2.9	3.0	

Note: An asterisk (*) indicates differences between participants and comparison group members that are statistically significant at p≤.05. (NS) stands for not significant.

Analysis

Analysis of the data uses a mix of multivariate regression approaches, depending on the types of data involved. The primary analysis uses a Repeated Measures Linear Mixed Models analysis for analysis of outcomes that are continuous variables. The "Mixed Models" analysis estimates average gains for participants vs. comparison students taking into account differences between the groups at baseline and using data from all points in time (baseline, post-program, and follow-ups). One advantage of this type of analysis for longitudinal studies is that the mixed analysis makes full use of cases with missing data, rather than excluding them from dataset (O'Connell and McCoach 2008, and Singer 1998). The study also incorporates Logistic Regression analysis to examine binary outcomes (for example, increase/no increase in STEM attitudes). All analyses include adjustments for differences between the participant and comparison groups at baseline, including covariates for gender, race/ethnicity, family income, participation in STEM honors courses at baseline (as a proxy for baseline STEM interest), and baseline parental support for STEM. The Mixed Models analysis of scale scores includes baseline scores for the scale being analyzed as a data point in the analysis (hence controlling for baseline differences); the Logit analyses include baseline scale scores as covariates for each scale being measured.

Findings

This paper focuses on the program's impact on a core set of STEM-related attitudinal measures at 48 months after program entry. Analysis of the data from earlier surveys (24 and 36 months after program entry) had found positive impacts on STEM-related attitudes for program participants.[3] The question for this paper is whether those positive impacts continued to persist as students continue through school and into college. As of the 48 month survey, less than half of the *FIRST* program participants responding to the survey were still involved in the program: 252 (41.2%) had graduated high school and were no longer eligible for *FIRST*, 128 (20.9%) had left the program, and 231 (37.8%) were still active participants.

As Exhibit 4 shows, the 48 month survey data continue to show shows a consistent, positive impact for *FIRST* participants on all five of the STEM-related interest and attitude measures. Based on the "Mixed Models" analysis, *FIRST* participants showed significantly higher scale scores at 48 months than comparison group students on all five measures after adjusting for differences at baseline. In each case,

[3] Earlier reports for the study are available on the FIRST website at: https://www.firstinspires.org/resource-library/first-impact.

the differences were significant at $p \leq .001$. The effect sizes for each impact were either "large" (the impact on STEM interest) or "medium," indicating that program impacts were not only statistically significant, but large enough to represent a meaningful difference in attitudes and interests.

Exhibit 4: Mixed Models Results: Impacts on STEM Measures at 48 Months, All Participants

STEM measures	Estimated Outcomes		Difference		Effect Size	
	FIRST	Comparison	Value	Sig.	ω^2	Strength
STEM Interest	4.13	3.70	0.37	0.000	0.15	Large
Involvement in STEM Activity	3.46	3.07	0.39	0.000	0.08	Medium
Interest in STEM Careers	4.33	3.71	0.62	0.000	0.09	Medium
STEM Identity	3.14	2.98	0.16	0.000	0.06	Medium
STEM Knowledge	5.63	4.99	0.64	0.000	0.07	Medium

Note: Controlling for Gender, Race, Honors Courses in HS, Family Income and parental support for STEM. Effect size measure is "Omega Squared" (ω^2). Effect size categories: Small >.01, medium >.06, large >.14

While the "Mixed Models" analysis indicated significantly greater gains in STEM-related attitudes for *FIRST* participants, a second analysis using logistic regression examined whether *FIRST* participants were more likely to show any gain between baseline and 48 months than comparison students. As Exhibit 5 shows, after adjusting for differences in baseline characteristics and baseline scale scores, *FIRST* participants were more likely to show gains on all five measures. The odds ratios from the Logit analysis show that *FIRST* participants were:

- 3.0 times more likely than comparison students to show gains on *STEM interest*;
- 2.2 times more likely to show gains in involvement in *STEM activity*;
- 3.0 times more likely to show gains on interest in *STEM careers*;
- 1.6 times more likely to show gains in *STEM identity*; and
- 2.2 times more likely to show gains in *understanding of STEM.*

All of those differences were highly significant at $p \leq .001$.

Exhibit 5: Logistic Regression (Logit) Results for STEM Scale Scores at 48 Months, All Participants

		Pct. With Increased Scores Baseline to Follow-Up (Unadjusted)		Relative Probability of Increase	
Measure	N	*FIRST* % Increase	Comparison % Increase	Odds Ratio	Sig.
STEM Interest	801	40.6%	27.7%	3.0	0.000
Involvement in STEM Activity	799	47.8%	38.4%	2.2	0.000
Interest in STEM Careers	709	43.5%	26.1%	3.0	0.000
STEM Identity	784	45.8%	45.3%	1.6	0.000
STEM Knowledge	775	51.5%	47.1%	2.2	0.000

Note: Controlling for Gender, Race, Honors Courses in HS, Family Income, parental support for STEM and scale at baseline.

Based on the "Mixed Models" analysis, positive impacts were evident for participants from all three *FIRST* programs in the study (Exhibit 6). Across all three programs *FIRST* participants showed statistically significantly higher scale scores than comparison students at the 48 month follow-up. With the exception of interest in STEM careers among *FIRST* LEGO League participants (who were younger than participants in *FIRST* Tech Challenge and *FIRST* Robotics Competition) effect sizes were either "medium" or "large" (the effect size for the impact on interest in STEM careers for *FIRST* LEGO League participants was "small.")

Exhibit 6: Mixed Models Results: Impacts on STEM Measures at 48 Months, by Program

Measure	*FIRST* LEGO League (N=206)		*FIRST* Tech Challenge (N=248)		*FIRST* Robotics Competition (N=366)	
	Difference (Sig.)	Effect Size	Difference (Sig.)	Effect Size	Difference (Sig.)	Effect Size
STEM Interest	0.347***	Medium	0.457***	Large	0.522***	Large
Involvement in STEM Activity	0.398***	Medium	0.279***	Medium	0.368***	Medium
Interest in STEM Careers	0.363**	Small	0.637***	Medium	0.848***	Large
STEM Identity	0.170***	Medium	0.165***	Medium	0.142***	Medium
STEM Knowledge	0.566***	Medium	0.647***	Medium	0.660***	Large

Note: "Difference" is the difference in scale score between *FIRST* participants and comparable comparison students at 48 months. Analysis controls for Gender, Race, Honors Courses in HS, Family Income and parental support for STEM. Significance: *p<.05, **p<.01, ***p<.001. Effect sizes (ω^2): Small >.01, medium >.06, large >.14

FIRST participants also showed significant impacts across all of the major population groups in the study and among participants from different types of communities. As Exhibits 7 and 8 show, male and female participants, White and Non-White, higher and lower income *FIRST* participants, and those from urban, rural, and suburban communities, all showed significantly greater gains than those of comparable students in the comparison group. In most cases, effect sizes were "medium" or "large."

Exhibit 7: Mixed Models Results: Impacts on STEM Measures at 48 Months, by Population Groups

	Males (N=738)	Females (N=521)	White (N=856)	Non-White (N=315)	Low Income (N=420)	High Income (N=701)
Difference in Estimated Outcomes at 48 Months						
STEM Interest	0.282***	0.578***	0.453***	0.307***	0.404***	0.457***
Involvement in STEM Activity	0.265***	0.507***	0.386***	0.344***	0.441***	0.367***
Interest in STEM Careers	0.325***	0.928***	0.661***	0.460**	0.654***	0.614***
STEM Identity	0.114***	0.212***	0.170***	0.126**	0.155***	0.171***
STEM Knowledge	0.349***	0.927***	0.664***	0.453**	0.637***	0.667***
Effect Sizes						
STEM Interest	Large	Large	Medium	Medium	Large	Medium
Involvement in STEM Activity	Medium	Large	Medium	Medium	Large	Medium
Interest in STEM Careers	Medium	Large	Medium	Small	Medium	Medium
STEM Identity	Medium	Medium	Medium	Small	Medium	Medium
STEM Knowledge	Medium	Large	Medium	Medium	Large	Medium

Note: "Difference" is the difference in scale score between *FIRST* participants and comparable comparison students at 48 months. Analysis controls for Gender, Race, Honors Courses in HS, Family Income and parental support for STEM. Significance: *p<.05, **p<.01, ***p<.001. Effect sizes (ω^2): Small >.01, medium >.06, large >.14

Exhibit 8: Mixed Models Results: Impacts on STEM Measures at 48 Months, by Community Type

	Urban (N=301)	Suburban (N=624)	Rural (N=277)
Difference in Estimated Outcomes at 48 Months			
STEM Interest	0.374***	0.458***	0.501***
Involvement in STEM Activity	0.422***	0.359***	0.449***
Interest in STEM Careers	0.730***	0.538***	0.778***
STEM Identity	0.202***	0.153***	0.175***
STEM Knowledge	0.706***	0.675***	0.618***
Effect Sizes			
STEM Interest	Large	Large	Large
Involvement in STEM Activity	Medium	Medium	Medium
Interest in STEM Careers	Large	Medium	Large
STEM Identity	Medium	Medium	Medium
STEM Knowledge	Large	Medium	Medium

Note: "Difference" is the difference in scale score between *FIRST* participants and comparable comparison students at 48 months. Analysis controls for Gender, Race, Honors Courses in HS, Family Income and parental support for STEM. Significance: *p<.05, **p<.01, ***p<.001. Effect sizes (ω^2): Small >.01, medium >.06, large >.14

While both young women and men in *FIRST* showed significantly greater gains than their comparison group counterparts, the gains for female *FIRST* participants were significantly greater than those for program participants as a whole (Exhibit 9). That is, young women in *FIRST* showed additional, statistically significant gains beyond those for *FIRST* participants generally.

Exhibit 9: Mixed Models Results: Differential Impacts on Females in *FIRST*

Measure	Difference in Outcomes - *FIRST* vs. Comparison	Sig.	Additional Impacts for *FIRST* Females (Female**FIRST* interaction)	Sig.
STEM Interest	0.270	0.000	0.326	0.000
Involvement in STEM Activity	0.263	0.000	0.250	0.009
Interest in STEM Careers	0.311	0.024	0.626	0.000
STEM Identity	0.111	0.003	0.102	0.020
STEM Knowledge	0.340	0.041	0.608	0.000

Note: "Difference" is the difference in scale score between *FIRST* participants and comparable comparison students at 48 months. Analysis controls for Gender, Race, Honors Courses in HS, Family Income and parental support for STEM.

An analysis of impacts by length of time in the program (one year vs. two or more years) shows that young people who participated in *FIRST* for only a single year still showed statistically significant gains relative to comparison students that persisted at 48 months; those who stayed in the program for two or more years showed even greater gains (Exhibit 10). It is important to note that those who persisted in the program beyond the first year were self-selected (rather than randomly assigned), so it is difficult to draw conclusions about the value of one year vs. two years in the program based on this data. However, the fact that even those who participated for only a single year showed significant impacts is notable.

Exhibit 10: Mixed Model Results: Impacts on STEM Measures at 48 Months, by Time in Program

	Marginal Means at 48 Months			Difference: 1 YR vs. Comparison		Difference: >1 YR vs. Comparison	
STEM measures	**1 Year in FIRST**	**2 or More Years in FIRST**	**Compar-ison Group**	**Value**	**Sig.**	**Value**	**Sig.**
STEM Interest	4.06	4.20	3.69	0.37	*0.000*	0.50	*0.000*
Involvement in STEM Activity	3.37	3.52	3.06	0.32	*0.000*	0.46	*0.000*
Interest in STEM Careers	4.16	4.48	3.69	0.47	*0.000*	0.79	*0.000*
STEM Identity	3.11	3.17	2.97	0.13	*0.000*	0.19	*0.000*
STEM Knowledge	5.51	5.75	4.98	0.53	*0.000*	0.77	*0.000*

Note: Controlling for Gender, Race, Honors Courses in HS, Family Income and parental support for STEM.

Finally, in order to examine the persistence of impacts beyond secondary school, the study also examined results for those participants who had graduated high school (and *FIRST*) and entered their first year at college. As Exhibit 11 shows, *FIRST*'s impacts in STEM-related interests and attitudes persisted among college-going program alumni. On all five STEM-related measures, *FIRST* alumni in their first year of college continued to show higher scale scores than college-going comparison students. All of those differences were statistically significant at $p \leq .001$. The effect size for those impacts were substantial, with "large" effect sizes for the impacts on STEM interest, interest in STEM careers, and STEM knowledge, and "medium" effect sizes on STEM activity and identity.

Exhibit 11: Mixed Models Results: Impacts on STEM Measures at 48 Months, First-Year College-Goers

STEM measures	**Estimated Outcomes**		**Difference**		**Effect Size**	
	FIRST	**Comparison**	**Value**	**Sig.**	**ω^2**	**Strength**
STEM Interest	4.25	3.73	0.52	0.000	.21	Large
Involvement in STEM Activity	3.45	3.08	0.36	0.000	.10	Medium
Interest in STEM Careers	4.40	3.64	0.76	0.000	.14	Large
STEM Identity	3.20	3.03	0.17	0.000	.10	Medium
STEM Knowledge	5.91	5.28	0.63	0.000	.15	Large

Note: Controlling for Gender, Race, Honors Courses in HS, Family Income and parental support for STEM. Effect size measure is "Omega Squared" (ω^2). Effect size categories: Small >.01, medium >.06, large >.14. N=451.

Discussion

A key question for this study is whether after-school robotics programs like *FIRST* are effective in promoting and supporting the kinds of interests and attitudes likely to lead to sustained involvement in STEM. The work of multiple scholars suggests that increased interest in STEM, a sense of STEM identity, an understanding of the relevance and utility of STEM in the real world, and the kinds of career opportunities available all promote increased involvement in STEM-related education and careers.

The data presented here suggests that these types of intensive, hands-on afterschool STEM experiences do have a positive and lasting impact on STEM-related attitudes and interests for middle and high school aged youth and that these impacts are substantial in terms of effect sizes. Longitudinal survey data collected over a 4-year period from *FIRST* participants and comparison students show positive, statistically significant impacts on a core set of STEM-related attitudes for program participants as a whole and for each of a number of key subgroups in the study sample, including both male and female participants, White and Non-White students, low and higher income participants, and students from urban and rural, as well as suburban communities. In most cases, not only were the differences in STEM-related attitudes and interests statistically significant, but the effect size measures indicate that the differences were large enough to represent a meaningful difference in attitudes and interests.

The data also suggest that these types of programs can have a positive impact across a range of ages. While the impacts were slightly less robust for participants in the *FIRST* LEGO League program, which targets late elementary and middle school students, versus the two high school programs in the study (the *FIRST* Tech Challenge and *FIRST* Robotics Competition), all three of the *FIRST* programs showed positive, significant impacts on participants. The results suggest that these programs can have a positive impact on both younger and older students.

The data also indicate that this type of after-school STEM program can have a particularly powerful impact on female participants. While the recruitment of young women into robotics programs like *FIRST* remains a challenge (approximately a third of *FIRST* participants are female), the young women who participated showed significantly greater impacts on STEM-related attitudes than the male participants in the program. Interviews with female program participants and responses to open-ended questions in the annual surveys suggest that many young women felt that *FIRST* had provided a unique opportunity to be exposed to engineering and robotics and to discover their own talents in what are traditionally seen as male-dominated fields.

Finally, the data from first-year college students in the study demonstrate that the positive impacts on STEM-related attitudes persist beyond high school and into college. At this point in time the data on college students must be seen as preliminary as the number of study participants who had entered college by the time of the 48 month survey is limited. However, the initial college data reported here and elsewhere suggest that not only do the impacts on STEM-related attitudes persist into college, but that they are reflected in the choices that *FIRST* alumni make about college majors, first-year courses, and engagement in STEM-related co-curricular activities (Burack, Melchior, and Hoover, 2018).

There are some important limitations to the study. The study uses a comparison group design (random assignment was not feasible) and there are significant differences in baseline attitudes between *FIRST* participants and comparison students. While the statistical analysis takes those differences into account, it is possible that there are unmeasured differences that are not reflected in the analysis. We continue to look for ways to further test our findings in that regard. The study also focuses on one particular group of programs (*FIRST*) in one STEM area of interest (robotics). Other robotics programs and other types of after-school STEM activities may have different outcomes. Ideally, other researchers can begin examining the broader array of after-school STEM programming. Finally, the 48 month data presented here represent interim findings for the study. Current plans call for collection of survey data for at least another year and likely beyond. With that additional data, we should be able to continue to examine even longer-term impacts on STEM-related attitudes as well as impacts on longer-term educational and career decisions.

At of this time, however, this study represents one of the only rigorous longitudinal studies addressing after-school STEM programming. The results to date suggest that these types of programs are an effective way of engaging and supporting young people's interest in STEM.

Appendix
STEM-Related Scales – Items and Sources

Domain	Source	Items
Interest in STEM	Brandeis University. Developed for *FIRST* Longitudinal Study (FLS) Alpha = .67	How interested are you in science, technology, engineering and/or math (STEM)? Please mark on a scale from 1 (Not interested) to 5 (Very interested). a. Science b. Technology c. Engineering d. Math
Involvement in STEM activities	Adapted from US Department of Education, High School Longitudinal Study of 2009 (Items c-f added). Alpha = .76	Other than for school, how much do you like to do the following? Please mark on a scale from 1 (Do not like at all) to 5 (Like a lot). a. Read science books and magazines? b. Visit web sites for information on computers and technology? c. Talk with friends or family about science and technology? d. Watch programs on science and technology on television (for example: Science Channel, National Geographic, Discovery Channel)? e. Design web pages? f. Take apart things (like motors, computers, toasters) to see how they work?
Interest in STEM careers	Adapted from Barker, 4-H Robotics and GPS/GIS Interest Questionnaire (items e-g added). Alpha = .81	How interested are you in each of the following jobs related to STEM (science, technology, engineering, and mathematics)? Please mark one response in each row using the scale from 1 (Not interested at all) to 7 (Very interested). If you are not sure, please give us your best answer. a. Scientist b. Engineer c. Mathematician d. Computer or Technology Specialist e. STEM Educator/ Teacher f. Inventor g. Skilled technician (for example: auto or aircraft mechanic, machinist, electrician, construction)
STEM identity	Adapted from US Department of Education, High School Longitudinal Study of 2009 (Items i-l added) Alpha = .70	Now we are going to ask you a few questions about your beliefs about math and science. How much do you agree or disagree with the following? a. I see myself as a math person. b. Others see me as a math person. c. Most people can learn to be good at math. d. You have to be born with the ability to be good at math. e. I see myself as a science person. f. Others see me as a science person. g. Most people can learn to be good at science. h. You have to be born with the ability to be good at science. i. I see myself as a technology person. j. Others see me as a technology person. k. Most people can learn to be good at technology. l. You have to be born with the ability to be good at technology.

Domain	Source	Items
Understanding of STEM	Center for Youth and Communities, Brandeis University, adapted from prior *FIRST* evaluation studies. Alpha = .94	We are interested in learning about how you think about yourself and your future. Using a scale from 1 (Not True at All for Me) to 7 (Very True For Me), please tell us how true each of the following statements are for you. a. I want to learn more about science and technology. b. I can use math and science to do something interesting. c. I have a good idea of what I want to study in college or technical school. d. I am interested in having a job or career that uses science and technology. e. I understand different ways that science and technology can be used to solve problems in the real world. f. I have a good understanding of how engineers work to solve problems. g. I know about a variety of jobs and careers in STEM (science, technology, engineering and/or mathematics). h. I have the kinds of skills that are needed to be a scientist or engineer. i. I can make a good living as a scientist or an engineer. j. I would enjoy working as a scientist or an engineer. k. I can use math and science to make a difference in the world.

Note: All alpha scores based on Wave 1 and Wave 2 baseline survey data, N=1273.

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