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Beyond Blackboards: Engaging Underserved Middle School Students in Engineering

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Abstract

Beyond Blackboards is an inquiry-centered, after-school program designed to enhance middle school students' engagement with engineering through design-based experiences focused on the 21st Century Engineering Challenges. Set within a predominantly low-income, majority-minority community, our study aims to investigate the impact of *Beyond Blackboards* on students' interest in and understanding of engineering, as well as their ability to align their educational and career plans. We compare participants' and nonparticipants' questionnaire responses before the implementation and at the end of the program's first academic year. Statistically significant findings indicate a school-wide increase in students' interest in engineering careers, supporting a shift in school culture. However, only program participants showed increased enjoyment of design-based strategies, understanding of what engineers do, and awareness of the steps for preparing for an engineering career. These quantitative findings are supported by qualitative evidence from participant focus groups highlighting the importance of mentors in shaping students' awareness of opportunities within engineering.

Keywords: underrepresented minorities, robotics, after-school activities, Grand Challenges, design-based research, mixed-methods

Introduction

As many studies have demonstrated, our nation needs to take significant steps to develop our STEM labor force, particularly in engineering (Engel & Giddens, 2011; National Academies, 2010a, 2010b; National Science Board, 2010). Yet, a lack of engineering-specific curricula throughout the K-12 pipeline results in an ill-defined path toward engineering for students (Chandler, Fontenot, & Tate, 2011). Further, the U.S. student body is diverse and includes increasing numbers of low-income, minority, and immigrant students. Racial, ethnic, gender, and social-class differences in interest and

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preparation appear as early as elementary and middle school, and early disadvantages produce persistent educational and labor force disparities that limit the diversity of students entering STEM fields (Gonzales et al, 2008; Riegle-Crumb, Moore, & Ramos-Wada, 2011; Riegle-Crumb & King, 2010). These differences in engagement are especially problematic because middle-schoolers' ability to align their educational plans and career goals may have long-term implications, particularly in STEM fields (Miller & Kimmel, 2012). Consequently, producing a larger and more diverse next generation of engineers requires that we improve underserved students' interest in, knowledge about, and ability to track toward careers in engineering at this critical time in their educational experiences.

This study investigates the impact of a research-based after-school program called *Beyond Blackboards*, a project rooted in the design principles of contextualized, inquiry-oriented instruction; socially relevant design problems; and collaborative problem solving. *Beyond Blackboards* uses mentored, designed-based inquiry to stimulate middle school students' engagement with engineering and enable them to better align their educational plans with their occupational goals. We report on findings from the program's first year within the Cave Creek School District (CCSD) in a predominantly low-income, Hispanic community in Texas.[1] Although Cave Creek is just outside a metropolitan area with a booming, innovation-driven economy,[2] it is miles away in terms of its demographics, education, and occupational possibilities for students. As with many low-income and majority-minority communities in the USA, Cave Creek's students and families have generally not had access to these opportunities, in part because they lack the education and skills required for technology-based careers. Thus, the salience of our analysis for increasing engagement and diversity in engineering is heightened by the geographic and economic context of the community in which our study took place.

Our study targets understanding students' attitudes and interests. We administered a questionnaire to students that addressed programmatic elements and also included items from the 2007 Trends in International Mathematics and Science Study (TIMSS), which allows us to empirically situate the relevance of our study by benchmarking the students in our study with their peers across the nation (International Association for the Evaluation of Educational Achievement [IEA], 2009). We then use an explanatory sequential mixed methods design (Creswell, 2014) to first investigate how the program impacts students' interest in and knowledge about engineering as well as the alignment of their educational and career plans via quantitative analysis before bringing qualitative evidence to bear in explaining our findings. Because such programs also have the potential to change the school culture by drawing attention and social prestige to students' engineering accomplishments (Coleman, 1995), we consider the program's impact on both program participants and their schoolmates. Taken collectively, our analysis contributes to understandings of (1) the engineering-related perspectives of middle school students from some of the most underrepresented populations in engineering, (2) how programs like *Beyond Blackboards* may shape participants' knowledge about, interest in, and plans concerning engineering, and (3) the extent to which such a program may produce shifts in these areas school-wide, among participants and nonparticipants alike.

Background

Encouraging and Supporting Engineering Careers among Middle-Schoolers

As students transition into middle school, many experience a decline in positive attitudes about mathematics and science (Gonzales et al., 2008), and even before high school, girls and members of racial minorities are less likely than boys and white students to aspire to careers in mathematics and science (Riegle-Crumb et al., 2011). These attitudes can have long-term effects on students' later career ambitions. Even at the elementary and middle school levels, schools can disrupt this downward trend by encouraging potential engineering students' interests and talents and by giving them the preparation and resources they need to pursue education in engineering-related fields.

However, many students do not know what engineers actually do or the role that engineers play in society. This lack of information may deter students from pursuing engineering degrees. Consistent with this argument, Jordan and Snyder (2013) found that even among participants in a middle school engineering club, "many students conceived of engineers as builders, repairpersons, or scientists. Few students identified more than two or three examples of what engineers design" (p. 1948). Conveying to students the important and dynamic role of engineers in society may increase students' interest in engineering, particularly among women and underrepresented racial or ethnic minorities (National Academy of Engineering, 2008).

Students may also lack an understanding of the types of skills and responsibilities required of engineers on a daily basis. In contrast to traditional mathematics and science courses, where students are typically encouraged to independently identify a single correct solution to problems, an engineering approach requires logical and divergent thinking, problem solving, communication of ideas, and teamwork. Along these lines, a National Science Foundation-published report recommends that engineers should possess "the ability to work in teams; a systems

[1] The names of the school district and community have been masked.

[2] The adjacent city was declared "recession-proof" by *Forbes Magazine* shortly before our study began (Zumbrun, 2008).

approach to problem solving; greater knowledge and consideration of social, environmental, and other implications of problem solving efforts; along with management skills and a capacity for life-long learning" (Coward, Ailes, & Bardon, 2000, p. 1). However, a study of students' drawings of engineers and scientists found that middle school students' views were antithetical to these recommendations; instead, they portrayed engineers as "doers" or "worker bees" rather than as problem-solving professionals engaged in critical thinking (Fralick, Kearn, Thompson, & Lyons, 2009). Therefore, educational opportunities that accurately highlight the skills needed for engineering may lead students to become more interested in engineering (National Academy of Engineering & National Research Council, 2009).

As students develop their educational and occupational goals, exposure to different types of careers can help them identify the pragmatic steps to take to achieve the careers they want (Buck et al., 2008; Csikszentmihalyi & Schneider, 2000; Hamilton & Hamilton, 1997). However, even when students aspire to a particular career and gain the necessary academic preparation in middle and high schools, many still fall short of their goals. One explanation for this unsuccessful transition is that students who are unclear or unfocused about their occupational futures tend to over- or underestimate the amount of education they will need for the type of career they wish to pursue (Schneider & Stevenson, 1999). If students are to succeed at their goals, it is important that they have "aligned ambitions"—educational expectations that align with occupational aspirations (Schneider & Stevenson, 1999). Students' ability to realize their career goals can be stifled if they are unable to clearly articulate or understand the pathways from secondary through postsecondary school and into careers. A recent study of long-term labor market outcomes found that young people who had underestimated the education required for their future occupations achieved, on average, lower levels of education and lower wages than those with high and aligned ambitions (Sabates, Harris, & Staff, 2011). These findings demonstrate that it is important for students' educational ambitions to align with their occupational goals.

While it is important for all students to be able to align their educational trajectory with their occupational goals, there is some evidence that this alignment may be especially important for STEM careers. Research suggests that potential STEM students often have difficulty identifying realistic strategies that will help them achieve their career goals. For example, students often do not know how to select coursework and extracurricular activities appropriate for STEM careers (Csikszentmihalyi & Schneider, 2000; Schneider & Stevenson, 1999). Additionally, middle school represents a critical point in which students are sorted into different math course levels based on their interests and performance—a mechanism that has long-term implications for their preparedness for college, STEM fields, and engineering in particular (Dauber, Alexander, & Entwisle, 1996; Miller & Kimmel, 2012). Engineering interventions and outreach need to help students develop realistic strategies to bridge their interests with the opportunities available to them during the complex transitional years of middle and high school.

The Call for Strategic Interventions

Schools must play a critical role in addressing these issues. Not only do schools have the capacity to increase students' knowledge about what engineering is, how engineers work, and how to align their educational and career ambitions, but schools can also influence students by creating a culture that promotes engineering. The National Academy of Engineering (2008) recommends that schools strategize to deliver messages that will affect how students perceive and evaluate STEM fields. For example, robotics competitions can positively influence participants' attitudes toward science (Welch & Huffman, 2011). Schools can also promote students' interest in and knowledge about engineering careers by shifting the curricular emphasis from mathematics and science achievement to proficiency in the types of skills required of engineers (National Academy of Engineering & National Research Council, 2009; Oware, Capobianco, & Diefes-Dux, 2007). These types of changes can improve potential engineering students' attitudes toward academic pursuits (Anderson, 1982; Thapa, Cohen, Guffey, & Higgins-D'Alessandro, 2013) and can even encourage them to put forth additional effort in school (Schunk, Pintrich, & Meece, 2008).

Several recent publications from the National Academies, National Science Foundation, and National Science Board address the declining competitiveness of the United States in the face of an increasingly technology-driven global economy. Each report describes ways that school climate can contribute to the production of engineers to meet the needs of this changing economy. While *Rising Above the Gathering Storm* (National Academies, 2007) emphasized the need for more inquiry-based learning in public schools, its 2010 update argued that developing a STEM workforce requires a "learning ecosystem" that includes school, family, and community members who cultivate and celebrate intellectual achievement (National Academies, 2010b). Combating low expectations, "math phobia," and peer hostility requires additional support for students and improved preparation for administrators and teachers (National Academies, 2010b).

Furthermore, K-12 schools can give students a more accurate and motivating impression of engineering by changing the ways that they portray engineering careers. Specifically, students are responsive to messages about the social importance of engineers as links between society and technology (National Academy of Engineering, 2008).

Particularly in the case of underrepresented minorities, interventions require adapting formal and informal science content to the culturally specific forces within a school (National Science Board, 2010). The *Beyond Blackboards* program was designed to address these recommendations by using the National Academy of Engineering 21st Century Grand Challenges to frame the curriculum.[3] Alongside their teachers and mentors, students explore and design engineering solutions for some of our world's most pressing social issues. Their *Beyond Blackboards* experiences are intended to help students get a sense of what their own engineering careers could be like.

School interventions can provide students with pathways into STEM fields.[4] Several studies have demonstrated that engineering outreach programs can improve students' mathematics and science content knowledge (Hotaling, 2007; McKay & McGrath, 2007; Mooney & Laubach, 2002; Schaefer, Sullivan, & Yowell, 2003). Other studies have demonstrated a link between such programs and students' learning and ability to explain, evaluate, or predict engineering concepts, processes, and outcomes (Barnett, 2005; Satchwell & Loepp, 2002). This study examines how the *Beyond Blackboards* program contributes to students' interest in and understanding of engineering as well as the extent to which students are able to align their educational and career ambitions. We also investigate the effect of the program on the school culture by considering these changes among nonparticipating peers.

Design-based Research, Cave Creek, and the Beyond Blackboards *Program*

Beyond Blackboards is an example of design-based research. According to Wang and Hannafin (2006), we define design-based research as "a systematic but flexible methodology intended to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories" (p. 6; see also Brown, 1992; Design-Based Research Collective, 2003). Educational researchers have argued that failing to consider the complexities of the learning context overstates the utility of experimental educational research; by contrast, design-based research takes an *in vivo* approach to producing plausible causal accounts within particular settings (Design-Based Research Collective, 2003; Johri & Olds, 2011). Numerous studies have demonstrated the effectiveness of this approach in generating theoretical understanding of the impact of interventions in K-12 engineering education (for example, Chiu & Linn, 2011; Marshall & Berland, 2012). The complexity of the *Beyond Blackboards* program, including the format of the program; the particulars of the local context; the multiple university, industry, school-district, and student actors; and the curriculum itself make it well suited for a design-based research approach. We now discuss each of these aspects in more detail.[5]

In fall 2010, *Beyond Blackboards* launched after-school robotics and engineering clubs at the CCSD's three middle schools. Teachers were recruited and provided with professional development to teach design-based learning and coach the clubs to compete in a FIRST LEGO League (FLL) competition. Each club had supporting undergraduate college students as well as industry mentors. Less than four months after the program began, student teams competed in a robotics competition, performed well, and in some cases won awards. The teams' successes drew media attention, which was heightened by the district's decision to host a regional qualifying competition. This attention generated community-wide pride over the accomplishments of the district's students.

The middle schools of CCSD offer a case study of some of the most underrepresented populations in engineering. Encompassing a cluster of seven small rural communities, the district has grown in recent years, primarily due to increasing numbers of low- and moderate-income Hispanic families. The school district reflects this shift: four out of five students are Hispanic, only 12 percent are black, and 5 percent are white. One in three students is classified as limited English proficient (LEP), and 87 percent of students are economically disadvantaged. Before the *Beyond Blackboards* program began, the district did not offer any outreach programs or informal educational experiences that would allow middle school students to become involved in STEM-related learning outside of the standard curriculum mandated by the State of Texas. Cave Creek students are an ideal target population for efforts to increase diversity in engineering and improve U.S. competitiveness.

CCSD collaborates with the engineering and education schools of a nearby university in a unique, ongoing partnership designed to implement the after-school robotics clubs and investigate their impact via design-based research. Open to all students, the *Beyond Blackboards* program includes after-school "Innovation Clubs" that were first implemented in the 2010–2011 academic year during the fall and spring semesters. All components of the *Beyond Blackboards* program present students with engineering-design challenges using LEGO® MINDSTORMS NXT robotics kits and the NXT-G programming environment. At each school, the Innovation Clubs met twice a week and

[3] http://www.engineeringchallenges.org/

[4] For a comprehensive overview, see Jeffers, Safferman, and Safferman (2004).

[5] For an overview of the approach to engineering education and more specifics regarding the curriculum of *Beyond Blackboards*, see the Appendix.

while the length of each meeting varied, the Innovation Club at each school had a total of 48 program hours during each semester. The research reported here focuses on the Innovation Clubs' first academic year.

Several community and university actors were involved in the implementation of the *Beyond Blackboards* program. The team from the university attended after-school activity nights organized by school personnel to introduce robotics and Innovation Club and to inspire student interest. Next, district and school staff coordinated club meeting schedules and student attendance while the team from the engineering school provided program materials and teacher training. During the 2010–2011 school year, the Innovation Clubs were led by two teachers at each of the three district middle schools. Prior to leading the clubs, these six teachers attended a professional development institute (PDI) facilitated by faculty members and graduate students at the university during the summer of 2010. At this PDI and at two follow-up PDIs during the school year, teachers received instruction and practice in design-based learning, the 21st Century Grand Challenges, automation and control, and how to construct and program robots using the LEGO products.

Additionally, undergraduate students served as technical mentors and role models for the students. The mentors attended orientation meetings to understand their roles and mentoring strategies and to develop expertise in LEGO robotics. Engineers from local companies served as industry mentors and worked alongside the teachers and undergraduates to provide support and a professional perspective. The presence of industry mentors often entailed exposure to engineering careers for the students. Through coordination among the Innovation Club teachers, the university, and community organizations, speakers from local companies also visited the schools to raise awareness of STEM career paths among students in Cave Creek.

In fall 2010, the Innovation Clubs coincided with the FLL season. FLL is a robotics competition affiliated with FIRST Robotics for students aged 9 to 14. Teams of up to ten students design LEGO robots to accomplish "missions" that are built around a particular societal need—for example, clean energy, food supply, or biomedical engineering. Teams receive points based on the number of missions they complete during two-and-a-half-minute trials. In addition, teams complete a research project related to the competition's theme and engage in community outreach to propose their solution. Each team is judged not only by the success of their missions, but also by the quality of their research project, their robot design, and their demonstration of FLL core values, including teamwork and gracious professionalism.

During fall 2010, *Beyond Blackboards* supported two teams from each of the three CCSD middle schools. Innovation Club participants were introduced to LEGO MINDSTORMS NXT through a series of directed robot-building laboratories and scaffolded instruction in NXT-G programming. After this introduction, teachers discussed strategies for prioritizing the missions for competition and explained the technical requirements for each mission. Teachers guided students as they designed their competition vehicles, and students chose research projects and developed their presentations for the competition. During the 2010 FLL season, all six teams participated in a qualifying competition, and three of the six teams were invited to participate in the regional championship. Also, one middle school in the district hosted a qualifying competition. As the season went on, the district began to embrace and celebrate the program and the students in the Innovation Clubs.

During spring 2011, the Innovation Clubs transitioned into a program developed by the team at the university around two of the National Academy of Engineering 21st Century Grand Challenges. For example, in "(Re)New Orleans," the program's curriculum guided students in designing solutions to restore and improve urban infrastructure using robotics. As a second example, in "Exploring Alternative Energy," students explored solar and wind power generation using LEGO MINDSTORMS NXT combined with other materials, including solar panels, wind turbines, and power meters.

Beyond Blackboards is motivated by the principle that all students can benefit from exposure to an engineering curriculum. Although not all students will enter the field of engineering, students gain problem-solving experiences, tolerance for ambiguity, understanding of systems thinking, and technological fluency (Partnership for 21st Century Skills, 2011). Through the *Beyond Blackboards* program and in conjunction with events organized by the school site for the community, CCSD parents also have the opportunity to engage in engineering concepts and activities designed by the university team as a part of the program's outreach component. *Beyond Blackboards* is an integrated program that gives middle school students, teachers, administrators, parents, and caregivers opportunities to participate in activities that will improve their understanding of STEM college and career pathways.

Research Objectives

Our study investigates the impact of the first year of the *Beyond Blackboards* program. Our research questions include: (1) In what ways does the program shape students' interest in, knowledge about, and understanding of how to prepare for a career in engineering among participants and nonparticipants? (2) How do students' descriptions of their own experiences account for these patterns?

We proceed in three parts. First, we empirically situate the relevance of our study by benchmarking the students of CCSD against the nationally representative sample in the TIMSS according to their backgrounds, school attitudes, and

educational expectations. Next, we quantitatively compare Innovation Club participants to their nonparticipant schoolmates to investigate changes in students' attitudes toward school, interest in and knowledge about engineering, and educational expectations following participation in *Beyond Blackboards*. Last, we bring students' own words to bear as we integrate qualitative data from focus groups into understanding how participation in Innovation Club may have shaped changes in students' interest in, knowledge about, and ability to align their educational plans with engineering career goals.

Based on our review of the literature in this area, we hypothesize that at an age when students' attitudes toward school generally worsen, participants will have heightened interest in and understanding of careers in engineering. Further, we expect school-wide effects such that the *Beyond Blackboards* program will enhance the prestige of STEM careers among nonparticipants, but that it will not improve their understanding of engineering careers or how to track toward them.

Data and Methods

Data Collection

The data for the quantitative component of this study were collected via surveys containing general academic items borrowed from the TIMSS (IEA, 2009) as well as original items concerning engineering interests, knowledge, and plans. The *Beyond Blackboards* research team collected these data during the 2010–2011 academic year, the first year of the program. CCSD includes three middle schools serving approximately 2,200 students that feed into the same high school; all three schools participated in the program and the data collection. All middle school students were targeted for a survey in September 2010, before the program began, and again in May 2011, after completion of the district's state-mandated standardized testing schedule. The research was approved by the university's Institutional Review Board and the school district. The pencil-and-paper questionnaires were short (approximately 15–20 minutes long), offered in English and Spanish, and completed by students on scannable answer sheets like the ones used by the district for benchmark testing. Student survey responses were then scanned into the district's data system, which automatically links with the district's administrative database.

According to year-end administrative records, 2,200 middle schoolers were enrolled in 2010–2011. Of these, 1,943 and 1,835 students completed the fall and spring surveys, respectively. Coaches reported on students' participation in *Beyond Blackboards*. Of the 80 participants listed, 74 were linked to their administrative records and 58 participants were surveyed in both the fall and the spring. Most non-completers were absent from school, not enrolled at the time of one of the surveys, or otherwise unavailable to sit for the questionnaire on the survey day. Table 1 shows the demographic characteristics of CCSD middle-schoolers compared with Innovation Club participants; this information is based on district records. Hispanic students were two-thirds of the participants, 18 percent of participants were white, and 14 percent were black. Three-quarters of participants were economically disadvantaged, 30 percent were female, and 27 percent were designated as LEP. Although Hispanics, girls, and economically disadvantaged students were underrepresented in the program, it included a relatively large number of these underrepresented students.

The questionnaire included items about students' interest in and understanding of engineering, attitudes toward school, and educational expectations. Students' interest in STEM careers and engineering in particular were measured using questions about students' interest in careers as scientists or engineers. Other items measured students' general interest in engineering ("I like learning how things work"), and understanding of how engineers work ("Engineers mainly work with other people to solve problems"). School attitudes were measured using students' responses to questions about whether they liked school, thought that most students tried their best, and thought that most teachers wanted students to do their best.

Table 1
Demographic information for Cave Creek middle schools.

	Cave Creek middle schools	*Beyond Blackboards* participants	*p*
Race/ethnicity (%)			***
White	5	18	
Black	12	14	
Hispanic or Latino/a	81	66	
Other	2	2	
Student background characteristics (%)			
Female	49	30	***
Economically disadvantaged	87	76	**
Limited English proficiency	32	27	
Number of students	2220	74	

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{+} < 0.10$.
Source: 2010–2011 Cave Creek School District administrative records and *Beyond Blackboards* participation records.
Note: Race/ethnic differences are established using Pearson's χ^2 test. All other differences are tested using a *t*-test.

All attitude measures asked students to respond "agree a lot," "agree a little," "disagree a little," or "disagree a lot." In analysis, the positive and negative responses were recoded as "agree" or "disagree." Last, students reported the highest level of education they expected to complete: finish high school, a two-year degree, a four-year degree, or an advanced degree; they could also indicate that they did not know. The questionnaire also included several items about students' family background, including their parents' level of education, whether they were born in the United States or elsewhere, and how often they used a language other than English at home.

Additionally, we use questionnaire items from the nationally representative, U.S. sample in the TIMSS. Although TIMSS includes measures of math and science attitudes, these pertain more closely to the math and science curriculum and classroom practices than to engineering (Gonzales et al., 2008). There were no references to engineering in TIMSS, nor were there questions about wanting a career in math or science. By contrast, the *Beyond Blackboards* surveys incorporated original measures of engineering attitudes and interest based on the program's focus on innovation, understanding how things work, and teamwork.

Focus Groups

The research team also conducted focus groups toward the end of the school year. Student focus groups were conducted at each school and lasted about one hour. The research team worked with the Innovation Club teachers to coordinate the student focus groups. A total of 19 students who were club participants near the end of the school year were able to take part in the focus groups; about one half of the students had been involved in the program since the fall semester. A focus group that lasted about an hour with five of the six teachers was conducted at the university and followed a half-day professional development session. The focus groups were not recorded; extensive notes were taken by at least one researcher and a research assistant during each focus group and were reviewed to add details immediately after each group. The focus groups followed an interview protocol aimed at understanding the students' and teachers' perspectives about the program and its impact. Students were asked about their motivation for participation, their engagement with the club, their perceptions of how their peers see the club, and how participation shaped their views of school, engineering, and problem solving. Every participant in each focus group had the opportunity to share their views. In the student focus groups, special attention was given to quieter participants as a way to encourage their input.

Analytical Plan

To contextualize the CCSD, we begin our analysis by comparing CCSD students with a nationally representative sample from the TIMSS. The TIMSS was administered to eighth-graders in the spring; to gain the most accurate comparisons, we use only eighth-grade CCSD students' responses from the spring survey. Using statistical tests, we compare Cave Creek students to their national counterparts according to their family background characteristics, race and ethnicity, school attitudes, and educational expectations.

Next, the quasi-experimental design of this study allows us to contrast the program participants with peers at the same school according to their school attitudes, engineering attitudes, and educational expectations. We compare participants' and nonparticipants' attitudes and expectations in the fall and spring, using one-sample *t*-tests for the dichotomous attitudinal measures and a chi-square test for students' educational expectations. Next, we estimate the mean change for the attitudes of participants compared with nonparticipants, and use a paired-sample *t*-test to estimate whether the average student change from fall to spring is significantly different from zero. While statistical tests for changes over time necessitate reducing our sample to only those students who were surveyed in both fall and spring, we report the fall and spring attitudes of all survey takers. This allows for the most accurate portrait of the CCSD student body at various points in time and allows future researchers to benchmark their data against our findings. We use a Friedman test to contrast the spring educational expectations with those from the fall for both participants and nonparticipants.[6]

Finally, we bring the qualitative evidence from our focus groups to bear to explain in students' own words how participation in Innovation Club may have shaped their interest in and understanding of engineering careers and their educational plans. This approach is consistent with an explanatory sequential mixed methods design in which qualitative analysis elaborates and expands on a set of quantitative findings (Creswell, 2014). To do this, two researchers from the team independently identified themes by open coding the interview records with the purpose of identifying aspects of participation that may have influenced students over the course of the year (Merriam, 2009; see also Knaggs, Sondergeld, & Schardt, 2015). After an iterative process, the researchers settled on the three themes described in the results section.

Results

Benchmarking Cave Creek against the U.S. TIMSS 2007

Before investigating the effect of *Beyond Blackboards*, we compare the eighth-grade CCSD students with the

[6] We replicated our analysis for the subsample of students who completed both the fall and spring surveys and found no differences in our results or interpretation. Therefore, to provide the clearest descriptive picture of our participants and nonparticipants in fall and spring, we include the full cross-sections in our analyses of students' fall and spring reports.

Table 2
Middle school student background and attitudes toward school.

	Eighth-graders		
	Cave Creek	TIMSS	*p*
Student background characteristics (%)			
Parent has a high school degree	62.74	88.25	***
Parent has an associate's or bachelor's degree	35.97	53.82	***
Student born in the U.S.	82.90	90.36	***
Student always speaks English at home	20.86	75.62	***
Race/ethnicity (%)			***
White	6.28	55.15	
Black	12.72	12.41	
Hispanic or Latino/a	79.71	23.38	
Other	1.29	9.06	
School attitudes (% agree)			
I like school	74.22	72.77	
I think most students try to do their best	60.36	52.98	***
I think most teachers in my school want students to do their best	90.64	88.65	
Educational expectations (%)			***
Finish high school	11.18	6.90	
Complete a two-year degree	7.89	8.39	
Complete a four-year degree	31.25	34.71	
Complete an advanced degree	38.82	41.30	
Don't know	10.86	8.69	
Number of students	621	7377	

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $+ < 0.10$.
Source: *Beyond Blackboards* spring 2011 survey and TIMSS.
Note. Student background characteristics and school attitude differences are tested using a *t*-test and race/ethnic and educational expectations differences are established using Pearson's χ^2 test.

sample of U.S. eighth-graders in TIMSS 2007. These results are reported in Table 2. The left-hand column shows the spring survey responses of CCSD eighth-graders. Compared with the nationally representative TIMSS students, Cave Creek students had parents with less education and were more likely to have been born outside of the United States. Only 21 percent of the students reported speaking only English at home, compared with 76 percent of the national sample. CCSD eighth-grade respondents are predominantly Hispanic (80 percent), compared with 23 percent in the national sample. Nonetheless, roughly three in four CCSD eighth-graders reported that they like school. While 91 percent of students reported that they felt that the teachers at their school wanted students to do their best, only 60 percent of all students agreed that their fellow students did their best in school. Although CCSD students differ significantly from their nationwide peers on background characteristics related to parents' education, nativity, ethnicity, and language use at home, there are no differences between CCSD and TIMSS students with respect to liking school and thinking that their teachers want them to do their best. In fact, Cave Creek students hold more positive attitudes about their peers' effort as they are more likely to report that students try their best.

The bottom part of Table 2 reports educational expectations for CCSD and TIMSS students. The largest share of CCSD middle school students (39 percent) reported intending to earn an advanced degree such as a master's, JD, or PhD; however, this figure is slightly lower than the national average (41 percent). Overall, a larger share of CCSD students than TIMSS students do not expect to complete a four-year degree or higher. The chi-square test revealed that the difference in educational expectations between CCSD students and the TIMSS sample is statistically significant, and that the main differences are that CCSD students are more likely either to not know their educational expectations or to only expect to finish high school.

Comparisons between Participants' and Nonparticipants' Attitudes over Time

Turning to the analysis of CCSD students and changes in their attitudes between fall and spring, Table 3 shows differences between participants and nonparticipants in fall and spring on the left and changes within these two groups over this period on the right. In fall, students who participated in the program were more likely than nonparticipants to like school. In spring, participants were less likely than nonparticipants to report that most students try their best. In general, school attitudes declined between the fall and spring. The mean changes over the year indicate that on average, students experienced a downward shift in thinking their peers tried to do their best at school.

Fewer participants reported that they liked school in the spring compared with the fall, and nonparticipants declined in their perceptions that teachers in their school wanted students to try their best over the course of the school year.

Students were also asked about engineering-specific attitudes. The left-hand side of Table 3 indicates that participants, compared with nonparticipants, were more interested in careers in science and engineering before they even enrolled in the *Beyond Blackboards* program. In spring, nonparticipants showed greater interest in becoming a scientist or engineer, and participants indicated greater interest in engineering only. Furthermore, whereas nonparticipants adopted more negative attitudes about learning how things work and demonstrated diminished understanding of the teamwork involved in engineering careers, *Beyond Blackboards* participants maintained their attitudes and understanding from the fall. These trends are confirmed by the measures of mean change on the right-hand side of Table 3. This suggests that the program may play a role in protecting participants from the usual decline in interest and attitudes, and that the program may have enhanced participants' interest in becoming engineers.

Last, the bottom of Table 3 shows differences between nonparticipants' and participants' educational expectations in the fall and in the spring. Although there are no fall differences, in spring more participants expected to earn a four-year degree or higher and fewer participants were unsure of their expectations (center column). No statistical differences were observed in the educational expectations of nonparticipants between spring and fall. However, within our small sample of participants, changes in educational expectations approach significance ($p = 0.11$). Two notable trends appear among the participants. First, in the fall, participants reported especially high levels of not knowing their educational expectations. This category is markedly reduced by the spring, suggesting that participants honed expectations over the academic year. A similar pattern is apparent for participants who began the year only expecting to graduate from high school; these students appear to raise their expectations during the academic year. Strikingly, participants' reports of "don't know" (18 percent) in fall far exceeds the TIMSS average for eighth-graders (shown in Table 2 as 9 percent), and drops below it in spring (5 percent). These patterns of change are not apparent among nonparticipants. The second notable trend distinguishing participants is that they showed a striking shift to reporting that they expect to complete a four-year degree, typically required for many engineering jobs, rather than an advanced degree. This is consistent with planning for a career in engineering which was reported by the majority of participants (71 percent). The shift in educational expectations for nonparticipants is simply toward an advanced degree, though a substantial portion of nonparticipants did not know their educational expectations or planned to only complete high school in the spring.

Unpacking the Program's Impact: Evidence from Focus Groups

To better illustrate why experiences in *Beyond Blackboards* affected students' interest in, knowledge about, and alignment of educational plans and career goals, we consider students' and teachers' own words about their experiences shared in focus groups. Three related themes that appeared consistently were: students' broadened perspectives of what engineers do, participants' increased motivation and confidence about their own engineering abilities, and the role of mentors in producing these changes.

Consistent with the quantitative analysis, participating in Innovation Club increased students' interest in engineering and their understanding of the link between engineering and innovation. One student offered, "When you see something you made or see something you worked on, you feel proud." Participants responded favorably to the teamwork, creativity, and challenges involved in competing against other teams. Another student described the excitement of competitions saying, "You got [to] see other teams, see their builds, [and] get new ideas for new builds. We all came together as a team. We were nervous. Adrenaline!" Participating in Innovation Club allowed participants to engage with supportive mentors in a different capacity than they normally experience in their classrooms. When describing their coaches, students reported how their mentors "were fun because they were helpful and show us what we did wrong…but you have to figure it out yourself." Students' new understandings of engineers as innovators clearly resonated with them; one student reflected that, "if people would actually take the time to learn how things work, we could probably fix a lot of stuff."

In addition to increased interest in engineering, participating in *Beyond Blackboards* broadened students' views of engineering opportunities and of their own potential as engineers. For example, one student reported that at first she wanted to be a teacher, but that after learning more about robotics from her coach, she now wants to be a chemical or civil engineer since "I've always liked building stuff, like with LEGOs." Another student described the appeal of the global opportunities associated with engineering: "I want to be an engineer because the speaker [an industry mentor] told us that engineers travel and I really want to go to Japan." Students also learned about their own interests and skills. A student reported that while participating, he found out that he was good with tools and now wants to be an engineer because "[he likes] building with wood, LEGOs, and other materials." However, some students were broadminded when describing how to apply their new skills. One student wanted to be "an FBI agent. I'm very curious about learning how things work, so I guess

Table 3
Students' attitudes and expectations in fall, spring, and changes over the school year.

	Differences between participants and nonparticipants in fall and spring						Differences within participants and nonparticipant groups between fall and spring			
	Fall			Spring			Percent change			
	Nonparticipants	Participants	*p*	Nonparticipants	Participants	*p*	Nonparticipants	*p*	Participants	*p*
School attitudes (% agree)										
I like school	73.96	86.21	*	73.56	75.86		0.00		−0.14	*
I think most students try to do their best	71.38	68.97		57.42	40.35	**	−0.13	***	−0.26	**
I think most teachers in my school want students to do their best	95.01	96.49		90.34	91.38		−0.05	***	−0.05	
Attitudes toward engineering (% agree)										
I would like to be a scientist when I grow up	23.62	48.15	***	26.73	46.55	***	0.05	***	−0.03	
I would like to be an engineer when I grow up	26.70	44.64	**	31.83	70.69	***	0.06	***	0.14	+
I like learning how things work	85.48	89.66		78.79	91.38	*	−0.08	***	0.00	
Engineers mainly work with other people to solve problems	73.86	79.31		64.14	82.76	**	−0.09	***	0.00	
Educational expectations (%)										
Finish high school	14.16	10.34		12.44	5.17	+	−1.29		−2.32	
Complete a two year degree	9.55	5.17		8.16	8.62	+	−0.82		4.65	
Complete a four year degree	27.67	18.97		28.81	39.66	+	1.23		13.95	
Complete an advanced degree	33.70	46.55		37.25	41.38	+	2.46		−6.98	
Don't know	14.92	18.97		13.35	5.17	+	−1.58		−9.30	
Number of students	1885	58		1777	58		1430		43	

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $+ p < 0.10$.

Source: *Beyond Blackboards* fall 2010 and spring 2011 survey data.

Note. Tests in the left and center columns indicate differences between participants and nonparticipants in the fall and spring (school attitudes and attitudes toward engineering tested with one-sample *t*-tests, educational expectations are tested using Pearson's χ^2). Tests on the right report whether the change between spring and fall within the subset of each group surveyed in both the spring and fall is significant (school attitudes and attitudes toward engineering tested with paired-sample *t*-tests, educational expectations are tested using a Friedman test).

that would help with being in the FBI since it's a mystery and you have to figure it out." In all, evidence from the focus groups suggests that students may have increased their interest in becoming engineers through learning more about engineering as well as their own strengths via participation and their mentors.

Participants in the program were not only developing long-term aspirations, but were adopting concrete strategies that can support their goals while they are in school—factors that may explain a shift in educational expectations among participants observed in the quantitative analysis. Multiple students reported plans to take pre-advanced placement (pre-AP) science and math. One girl in eighth grade explained, "I got better at math. The mentors (from the university) talk about rotation and distance of things. I'm in a regular math class, but I have a 100… Next year, I am taking Algebra." In addition, students also gained an enhanced understanding of engineering skills such as problem solving and critical thinking. One student reported improving at problem solving which "helped [her] focus more in school… [like] with answering questions." A teacher coach noted that, "I had a child that was trying to do a build, and he was getting frustrated… [When] he finally got it, his robot was working and he was absolutely thrilled." She added that,

> Through robotics, students learned problem solving and analytical thinking skills. The higher-level thinking, it's everywhere; the government wants us to go with higher-level thinking and STEM.... College readiness? Yeah! These kids will be problem ready, [ready] for industry, teamwork.

Beyond Blackboards may shape middle school students' goals not only by exposing them to engineering, but also by enhancing their confidence in their ability to solve problems and to be academically competitive in high school and beyond.

Discussion and Conclusion

Beyond Blackboards represents a possible response to the call to broaden access to STEM fields and increase awareness of the engineering profession, especially for traditionally underrepresented groups (National Science Board, 2010). The CCSD serves underrepresented students who could take advantage of the rich opportunities in the larger metro area if they gain the education and training to do so. Our comparison with the national TIMSS 2007 sample demonstrates that although the CCSD students' attitudes toward school are similar to or, in some cases, more positive than those of their national peers, they have lower educational expectations. *Beyond Blackboards* is designed to encourage students to engage with engineering and pursue relevant educational opportunities. The approach is systemic in that it is designed to engage the entire school community and stimulate interaction between parents, industry mentors, undergraduates, district administrators, and other community members. The goal of these activities is to pave the way for students to embrace engineering, consider engineering careers, and align their educational and occupational ambitions.

We set out to investigate the impact of the *Beyond Blackboards* program on three outcomes critical to the engagement of underserved students with engineering. Specifically, we examined whether *Beyond Blackboards* increased participants' interest in, knowledge about, and understanding of how to prepare for a career in engineering. Our findings show that *Beyond Blackboards* participants, who were initially more interested than their schoolmates in engineering careers, gained even greater interest over the academic year. Further, we document a trend of increased interest in four-year degrees over undefined or highly ambitious postgraduate degrees among participants, which suggests that these students were aligning their ambitions around the skills required of them to pursue careers in engineering. Although these early results are suggestive of program impact rather than conclusive, our qualitative data from focus groups support that participants have changed the way they think about engineering.

Further, we examined whether the program's impact might extend to nonparticipants as well. We found possible evidence of this systemic impact on the broader school culture. During adolescence, when students' attitudes toward school typically decline (Riegle-Crumb et al., 2011), CCSD students experienced positive changes in attitudes toward STEM careers in general and engineering in particular. Strikingly, both participants' and nonparticipants' enthusiasm increased, suggesting that middle-schoolers' enthusiasm for science and engineering appears to have increased district-wide. However, compared with participants, nonparticipants were less likely to enjoy learning how things work or to report that engineers mainly work with other people to solve problems. Our qualitative evidence underscores the role of coaches and industry mentors as key sources of information about engineering opportunities for participants. Therefore, although nonparticipants moderately raised their educational expectations, they did not share in the trend among participants of focusing educational expectations around the concrete goal of a career in engineering or science. This suggests that although interest in engineering and science careers increased for all students following the implementation of the *Beyond Blackboards* program, those who did not participate did not enjoy the benefit of increased understanding of what these careers were like and what is required to obtain them.

Recall that the program takes a design-based approach to solving socially relevant problems. This approach could contribute to the outcomes we observe in several ways. As

evidence from the focus groups suggests, the program participants' experiences in teams working on difficult problems that have more than one possible solution may have bolstered students' confidence that they can solve such problems, that it is acceptable to take risks and try various solutions, and that working as a team can be rewarding. It also gave them a hands-on, experiential view of what an engineer does—a critical step in developing aligned ambitions (Schneider & Stevenson, 1999).

The early success of the FLL teams may have contributed to the school-wide shift in attitudes about STEM. Teachers, students, administrators, parents, and community leaders all took note and were proud of the teams' successes. Successes were featured in the local news, on school and district web sites, and in school-wide assemblies. This attention may have contributed to the positive shift in students' attitudes about STEM that we observed even among students who did not participate.

Although our results are consistent with the idea that incorporating design principles shapes students' engineering knowledge, ambitions, and plans as well as the school-wide climate surrounding engineering, our findings are suggestive rather than conclusive about the *cause* of the observed changes. Further evidence is needed to ascertain whether and how *Beyond Blackboards* has an effect on participants and their schoolmates and to determine why it contributes to changes in attitudes, interests, and expectations. Our comparisons between students' fall and spring survey responses demonstrate overall changes among both participants and nonparticipants in a setting composed predominantly of students who are traditionally underrepresented in engineering—namely, students who are Hispanic, economically disadvantaged, and often speak languages other than English at home.

Throughout the analysis, we were sensitive to issues of self-selection and potential sources of selectivity among our respondents. For example, students who participated likely differed from those who did not in motivation and in the circumstances that enable participation, and this is reflected in the participants' highly positive views toward engineering in the fall. In this light, our finding that students' interest in engineering increased may seem obvious; however, one possible alternate scenario would be that as students gained clearer understandings of what engineering entails, their interest in engineering could have declined. Still, we wanted to be sure that selectivity into participation was not driving our results and that our findings would hold true for minority and low-income students. As a feasible robustness check, when we restricted our analysis to the subsample of Hispanic students and to economically disadvantaged students, the results were consistent with our conclusions. Our sample size precluded such testing for girls, English-language learners, and other minorities, but we encourage future research in this area. However, this preliminary check suggests that the positive association between participation and attitudes toward engineering and careers in engineering is shared by underrepresented students and their more privileged classmates alike.

It may be helpful for future investigations to extend this line of inquiry further as well as identify the extent to which students benefit from team membership in general versus particular roles and experiences. For example, *Beyond Blackboards* could affect students differently depending on whether they assumed a leadership role in a large team or worked in a smaller, more egalitarian group. Nonetheless, we have provided important new evidence for the value of programs such as *Beyond Blackboards*; in particular, we observe a striking school-wide shift in STEM-related interest, and we did not observe a concurrent shift in more general attitudes about school. We collected the data for this analysis during the first year of the program, which brings with it certain limitations, such as small sample size and a smaller window of time to observe changes among Cave Creek students. These limitations were necessary, however, because the first year of implementation is the only window of opportunity to observe any shift in school-wide culture from the introduction of a new program.

The CCSD provides an excellent venue for an intervention such as *Beyond Blackboards* to take hold broadly across all middle schools in the district and contribute to promoting diversity in our future engineering labor force. As a relatively small, rural, and tightly knit community of working-class and poor families with limited education, the Cave Creek community cares about providing opportunities for its children. *Beyond Blackboards* is broadly appealing to this community because it encourages students to consider a future in the STEM fields; aligns students' ambitions; and brings together students, teachers, and families around activities that connect to future educational and career opportunities.

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Appendix

A. Beyond Blackboards: Engineering and curricular aspects of the program.

Foundations of engineering education approach	*Beyond Blackboards* curriculum
Principles of K-12 engineering (National Academy of Engineering & National Resource Council, 2009) • An emphasis on engineering design and the design process • Incorporation of important and developmentally appropriate mathematics, science, and technology knowledge and skills • Promotion of engineering habits of mind: (1) systems thinking, (2) creativity, (3), optimism, (4) collaboration, (5) ethical considerations	Based on the 21st Century's Grand Engineering Challenges (National Academy of Engineering, 2008) Themes: sustainability, health, reducing vulnerability, joy of living Example units: • "Engineering entrepreneurship" where students formed Grand Challenge companies • "Relay for a Reason" where students applied robotics solutions to natural disaster relief • "Biomedical Outreach and Leadership Team" (BOLT) where students learned about biomedical design innovations
Mode of learning: design-based, project-focused, hands-on activities incorporating applied mathematics and science	Extension to careers: STEM Stations included in each meeting emphasizing real-world applications of disciplinary integration of science, technology, engineering, and mathematics
Source: *Engineering in K-12 education: Understanding the status and improving the prospects* (National Academy of Engineering & National Resource Council, 2009).	Source: *Changing the conversation: Messages for improving public understanding of engineering* (National Academy of Engineering, 2008).