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A middle school engineering outreach program for girls yields STEM undergraduates

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Abstract

Many engineering units within universities continue to work toward gender parity among their undergraduates. One strategy is to offer STEM enrichment programs for young women. Experts agree that middle school is an optimal time for intervention, and numerous studies show that middle school outreach programs for girls can enhance interest in STEM. Some universities, however, may be hesitant to invest in middle school programming without evidence of long-term impact. This study shows that rising 7th grade girls who participated in a two-week residential engineering enrichment program at a STEM-intensive university later applied as undergraduates, were admitted, and enrolled at higher rates than a control group. The experimental design of this study is relatively unusual for middle school enrichment programs and eliminates potential bias due to self-selection or a competitive application process.

Introduction

The question of diversity in science, technology, engineering and mathematics has been a topic of research for close to half a century. In spite of numerous efforts to diversify STEM (Science, Technology, Engineering and Mathematics) and definite progress in some disciplines, we still have a long way to go to reach gender parity, especially in engineering. In 1998, the percentage of first year college women who entered engineering was 2.7%. In 2014, that number was 5.8% of all first year women (National Science Board, 2016).While this represents a 100% increase in the representation of women among first year engineering students, it pales in comparison to overall representation of women students in four year institutions, which reached 57% in 2014. Clearly, work to increase gender diversity in engineering must continue (Pryor, Hurtado, Saenz, Santos & Korn 2007; National Research Council, 2006).

The paucity of women in engineering is particularly evident at technical institutions where most students major in a STEM discipline. As such, these institutions face a significant gender disparity in their student populations. For example, at the university where this research was conducted, approximately 96% of undergraduates are working toward degrees in engineering, the natural sciences, mathematics, or computer science. Thirty-three percent of the student body is female. These data are typical for most of our peer technological institutions with similar offerings and is consistent with national data which indicate that 25.8% of first year women intend on majoring in STEM disciplines, with a breakdown as follows: biological/agricultural sciences (15.8%), mathematics and computer science (2.1%), physical sciences (2.1%), and engineering (5.8%) (National Science Board, 2016).

In 2006, the National Research Council (NRC) Committee on Women in Science and Engineering recommended that universities extend outreach to potential students through a variety of programming including summer science and engineering camps, lecture series, career days, collaborative research projects, and support for K–12 teachers (NRC, 2006). In the intervening decade, STEM pipeline programs at the middle and high school level have been offered by many institutions to build equity and encourage girls to consider STEM careers. Especially in times of budgetary constraints, a key question is whether higher education institutions can and should continue to invest in these pre-collegiate programs, particularly at the middle school level, without evidence of long-term impact such as greater entry into college STEM majors or direct recruitment benefits to the university. While an increasing number of longitudinal studies have suggested that positive short-term outcomes of middle school programs can be sustained and translate to those long-term outcomes, many of these studies have serious methodological limitations. With its experimental control-group design, this paper contributes to the field by demonstrating that a middle school engineering pipeline program can be an effective college recruitment tool.

Literature Review

Middle School as an Important Time for Intervention

Much of the literature related to the effectiveness of out of school time or informal pipeline programming suggests the need to start early to support girls in STEM: elementary or middle school (Hughes, 2015; Leaper, 2014; Heaverlo, Cooper, & Santos Lannan, 2013; Valla & Williams, 2012; VanLeuvan, 2004; Fadigan, & Hammrich, 2004; Clewell, 2002; Clewell & Campbell, 2002). Many of the factors that negatively influence women from choosing STEM majors and careers take shape early in a girl's life. These factors include poor science identity, low self-efficacy in math, gender stereotypes and stereotype threat, lack of role models, misalignment between perception of STEM careers and personal values, and low interest in STEM subjects. For example, VanLeuvan (2004) found that girls' interest in math and science dropped by about 15% between middle and high school. Moreover, low confidence and self-efficacy in STEM subjects form as early as grade six (Heaverlo et al., 2013). Early intervention to mitigate negative influences can ultimately have an effect on a women's choice to enter STEM (Young, Ortiz, & Young 2017; Bieri Buschor, Berweber, Keck Frei, & Kappler, 2014; Hughes, 2015; Wang & Degol, 2013; Heaverlo et al., 2013).

The Efficacy of STEM Outreach Programs for Middle School Girls

Numerous studies have shown positive outcomes of outreach programming at the middle school level. Most middle school programming aims to build interest in STEM, which can become a factor in decisions about college major and career path (Hall, Dickerson, Batts, Kauffmann & Bosse, 2011; Tsui, 2009). From a meta-analysis of 15 studies of out-of-school time STEM programs at the elementary, middle school, and high school levels, Young, Ortiz, and Young

(2017) concluded that out-of-school time has a positive effect on student interest in STEM at the middle school and high school level, regardless of student gender. Additionally, middle school intervention programs can have a positive effect on STEM identity, help mitigate negative peer pressure, and neutralize adverse influences such as stereotype threat (Hughes, 2015; Wang & Degol, 2013).

Growing evidence points toward the effectiveness of peer support and positive role models within interventions. For example, Leaper (2014) assessed the influence of a women's peer group on underrepresentation in STEM and found that peer support is positively associated with achievement, which in turn is associated with interest. Young, Ortiz, and Young (2017) found that successful intervention programs had both an academic and a social component incorporated. In addition, numerous studies have demonstrated the benefits of positive role models (Hughes, 2015; Bieri Buschor et al., 2014; Demetry & Sontgerath, 2013; Fadigan & Hammerich, 2004).

Middle School Outreach as a Recruitment Strategy: Implications for Program Evaluation

Universities are in a good position to offer high quality outreach programming because of their ability to connect girls with a wide range of positive role models in STEM disciplines and to offer hands-on experiences in science and engineering laboratories. Our examination of data collected by the Engineering Education Service Center (EESC) suggests that 147 universities across the United States are offering more than double the number of STEM enrichment programs at the high school level than at the middle school level (EESC, 2017). Delivering budget-neutral programs to families at all socioeconomic levels typically demands substantial fundraising. Given the considerable effort and resources required to plan and deliver high quality programming, perhaps the most salient metrics of success from an institutional and donor perspective would be evidence that middle school programs attract more women into STEM majors, benefiting higher education and society in general, or that programs provide direct value to the institution in terms of recruitment.

Based on the many social psychological factors that inhibit women from entering STEM disciplines, recruitment strategies targeting women are critical to increasing diversity at technological institutions or within schools of science or engineering at larger universities. In a study of mechanical engineering programs that graduate a large number of women, Tsui (2009) found numerous examples of using community outreach and undergraduate role models to bolster recruitment, but also concluded that more female-focused recruitment was necessary. We found several publications directly stating that the success of university outreach programs, both at the middle school and high school level, would be measured by direct recruitment into STEM majors at the university (Landgraf, Peters, & Salmon-Stephens, 2008; Zurn-Birkhimer & Holloway, 2008).

Most middle school outreach programs for girls can demonstrate short-term effects such as enhanced interest in STEM, but data about college choice and major selection are more challenging to collect because of the time lag between middle school and college entry. Among middle school programs that have tracked long-term effects, some found that interest in STEM eroded (VanLeuvan, 2004; Jayaratne, Thomas, & Trautmann, 2003). Others found lasting positive outcomes that didn't always reach the point of statistical significance (Demetry, Hubelbank, Blaisdell, Sontgerath, Nicholson, Rosenthal & Quinn, 2009; Tomhave, 1990; Virnoche & Eschenbach, 2007; Virnoche, 2008). Other studies that have suggested long-term effects have methodological limitations, most commonly the failure to control for self-selection or other biases. For example, Zurn-Birkhimer & Holloway (2008) reported that a university's STEM summer camps targeted at 5^{th} to 8^{th} grade girls resulted in a 26% matriculation rate to the university. However, that outcome is difficult to attribute to the camp since participants chose to apply and then were selected in a competitive process based on essays and letters of recommendation. University support for middle school outreach programs for girls could be bolstered by well-designed longitudinal studies that show positive outcomes for direct recruitment or entry into STEM majors. Experimental designs with control groups remain the gold standard (Valla & Williams, 2012). This study helps to close that gap.

Background about Camp Reach

WPI has offered Camp Reach, a two-week residential, engineering-focused summer program for 30 rising 7^{th} grade girls, annually since 1997. Previous publications describe the program design features and rationale in detail (Demetry et al., 2009; Demetry & Sontgerath, 2013). Key programmatic elements include:

- A service learning project wherein teams of girls use the engineering design process to propose a solution to a real-world problem posed by a non-profit organization
- Hands-on design activities in a variety of engineering disciplines, chosen to emphasize the human and social context of engineering—that engineers can make the world a better place
- A focus on collaboration and teamwork in both academic and social activities
- Exposure to numerous female role models and mentors with interests in STEM, including high school students, undergraduate and graduate students, and practicing engineers and scientists
- Regular opportunities through middle school and high school to reconnect with program peers and role models at reunions, as a staff member, or through other university programs

From the perspectives of Camp Reach participants in one study (Demetry & Sontgerath, 2013), the program elements with the most lasting positive impact were returning to the program as a staff member, the prevalence of role models, and the teamwork infused in all activities.

The selection of Camp Reach participants was designed to enable creation and tracking of a Control group. The application requires only an essay; no measures of academic achievement or potential are requested. Program participants are selected from the applicant pool using a random lottery for the 30 available spots. The applicants who are not selected are placed in the Control group.

In previous longitudinal studies, we investigated outcomes such as STEM-related course-taking in high school, STEM-related self-efficacies, knowledge of and attitudes about engineering, and choice of college major (Demetry et al., 2009; Demetry & Sontgerath, 2013). Camp Reach alumnae and girls in the Control group were interviewed by telephone six years or more after they applied to Camp Reach as sixth graders, with response rates between 40-70%. We asked Camp Reach alumnae whether they had returned after the camp for a follow-up activity, reunion, or another WPI program. Those data were used to create two subgroups: subjects in Reach Partial participated only in the two-week summer camp as a rising seventh grader, while those in Reach Full returned for at least one follow-up activity, reunion, or program.

Both previous studies suggested that multiple interventions are associated with stronger outcomes. For example, six or more years after their 6^{th} grade application to Camp Reach, those alumnae who had returned at least once for a reunion or another program showed more accurate perceptions of engineers and engineering compared to the Control group. However, those who participated only in the two-week summer camp (the Reach Partial group) had similar perceptions as those in the Control group.

For the first five years of the program (1997-2001), 18% of Reach Full study participants declared engineering majors in college, compared with 3% in the Control group (Demetry et al., 2009). Expanding to include majors in the sciences and science-based professions (e.g., nursing), 47% of the Reach Full group was pursuing those pathways, compared to 29% of the Control group. Alumnae in the Reach Partial group had chosen STEM majors at the similar, lower level of the Control group (Demetry et al., 2009).

In recent years we noticed an increasing number of Camp Reach alumnae applying to WPI. Although direct recruitment to our university was never an objective of this middle school program, we were interested in exploring that possible outcome.

Methods

Research Question

In this study, we used admissions records to investigate the following question: Have individuals in the Camp Reach group applied to, been accepted at, and enrolled at WPI at a greater rate than individuals in the Control group?

Using admissions records rather than contacting subjects allowed inclusion of 100% of the possible sample in the study. We submitted a proposal to the WPI Institutional Review Board to query the WPI admissions database without consent of the subjects, recording the information in such a way that subjects could not be identified. The study protocol was approved and granted an exemption (#15-187).

Sample

The study sample was comprised of the 731 applicants to Camp Reach from 1997 to 2010, all of whom were in sixth grade at the time of application. All subjects were Massachusetts residents or lived within a 50-mile radius of WPI. Their application suggests openness to the idea of pursuing STEM education pathways as sixth graders. The application consists of an essay, but selection is not based on essay quality or any other measure of achievement or potential. As explained previously, 30 program participants were chosen from the applicant pool each year by lottery. In some years the selected cohort was adjusted to be consistent with the racial diversity of our county. This override of the lottery system rarely exceeded one or two girls. Those girls who were selected and completed the two-week summer program were placed in the Reach group (n = 419). All of the girls in the Reach group were also invited to participate in a variety of follow-up gatherings and programs in their middle school and high school years. Applicants who were not selected in the lottery, and any girls who started the two-week summer program but did not complete it, were placed in the Control group (n = 312). Table 1 shows the number of girls in the Reach and Control groups by program year.

Data Collection

Names and birthdates of the 731 subjects were compiled from program records for the years 1997 through 2010. We then collected three data points for each subject from admissions records: whether she applied as an undergraduate (yes = 1, no = 0), whether she was accepted (yes =1, no = 0), and whether she enrolled (yes =1, no = 0). We used two methods to query WPI admissions records:

1) An admissions staff member manually searched the database for each subject's name. If the name was found and the birth date also matched, she recorded a "1" if the subject applied as an undergraduate, a "1" if she was accepted for admission (0 if denied), and a "1" if she ultimately enrolled at WPI as an undergraduate (0 if she declined the offer). Students who

applied and were placed on the Waitlist, without ultimately being offered admission, were coded as 1-0-0 for Applied-Admitted-Enrolled. Students who applied and enrolled as undergraduate transfer students were coded the same as regular applicants. If the name and matching birth date were not found in the database, the staff member concluded that the subject did not apply to WPI, and zeroes were recorded for Applied, Admitted, and Enrolled.

Table 1. Number of Girls in Study Sample, By Year

Program Year	Camp Reach	Control	Total
1997	30	*	30
1998	29	13	42
1999	27	20	47
2000	30	39	69
2001	29	40	69
2002	30	39	69
2003	30	17	47
2004	30	16	46
2005	28	12	40
2006	30	18	48
2007	30	39	69
2008	30	36	66
2009	30	23	53
2010	36**	0	36
Total	419	312	731

Notes:
* No records could be found for the Control group in 1997.
** In 2010 the program was enlarged to accommodate up to 40 participants. All 36 girls who applied were accommodated and completed the program.

2) An automated method was used to cross-check the data gathered manually, using a combination of SQL, RStudio, and Python programming. An information analyst wrote a script to query the admissions database and filtered records of applicants who: a) identified as female; b) applied for admission in the fall of 2003 or later; and c) had birth years earlier than 1983. (Girls in the first cohort in 1997 would have applied for admission as an undergraduate in 2003 if following a typical schedule, and the earliest birth year in Camp Reach records was 1984.) At this point the admissions dataset included more than 38,000 records. This admissions file and the Camp Reach applicants file were then queried to identify records that

matched exactly: first name, last name, and date of birth. In addition, close matches were identified for follow-up examination (matching first name and birthdate but different last name, match for birthdate and first three letters of last name). Binary data (0,1) for Applied, Admitted, and Enrolled were then recorded for each subject in the same manner as described for the manual process.

The results of the manual and automated processes were then crosschecked, and discrepancies between the two datasets were investigated and reconciled. Initially, the automated process missed some applicants that had been found manually, which helped to identify and correct a programming bug. In addition, the automated process revealed some inaccuracies in the manual dataset. Moreover, the process of identifying "close matches" proved helpful in finding some admissions records that had been missed due to last names that had been spelled incorrectly when transcribed from paper applications (e.g., a last name had been entered incorrectly as Edmonson instead of Edmondson.)

While the combination of manual and automated data collection methods yielded greater accuracy and confidence in the final dataset, there were still some limitations related to missing or possibly inaccurate birthdates. Application data from four subjects in the sample did not include birthdates. Birthdates on five paper applications were difficult to read, and the best guess had been recorded. In addition, four birthdates were obviously incorrect; the applicant or her parent/guardian had written the year of application instead of the birth year. In these cases, an educated guess had been made based on the birth years of other applicants in the same cohort. Because of the uncertainty in birthdates for these 13 cases, the admissions database was queried to identify matches of first name and last name only. No matches were found for these 13 names, using either the manual or automated process. Given the large sample size, any remaining inaccuracies in the data are not likely to affect the conclusions of the study.

Analysis

The SPSS software package was used for quantitative data analysis. Contingency tables were created to compare the number of subjects in the Reach and Control groups who applied for admission to WPI, were accepted, and enrolled. Pearson's chi-square test was used to determine whether differences between the two groups were statistically significant.

Results

Tables 2, 3, and 4 present the number of subjects in the Reach and Control groups who applied to WPI, were accepted, and enrolled. For all three admissions measures, chi square tests of independence revealed a significant relationship between group membership and admissions outcome. Alumnae of Camp Reach were more likely than those in the Control group to apply, be admitted, and enroll at WPI ($p < 0.005$). The acceptance rate was somewhat higher for the Reach group (85%) than for the Control group (73%). The admissions yield, defined as the percentage of accepted applicants who enrolled, was 44% for the Reach group compared to 31% for the

Table 2. Number Who Applied for Undergraduate Admission to WPI, by Group*

Study group		Applied	Did not apply	Total
Camp Reach	Count	92	327	419
	Percent	*22.0%*	*78.0%*	*100.0%*
Control	Count	40	272	312
	Percent	*12.8%*	*87.2%*	*100.0%*
Total	Count	132	599	731
	Percent	*18.1%*	*81.9%*	*100%*

*X^2 (1, N=731) = 10.09, $p = 0.001$

Table 3. Number Accepted for Admission to WPI, by Group*

Study group		Accepted	Not accepted	Total
Camp Reach	Count	78	341	419
	Percent	*18.6%*	*81.4%*	*100.0%*
Control	Count	29	283	312
	Percent	*9.3%*	*90.7%*	*100.0%*
Total	Count	107	624	731
	Percent	*14.6%*	*85.4%*	*100%*

*X^2 (1, N=731) = 12.44, $p < 0.001$

Table 4. Number Who Enrolled as an Undergraduate at WPI, by Group*

Study group		Enrolled	Did not enroll	Total
Camp Reach	Count	34	385	419
	Percent	*8.1%*	*91.9%*	*100.0%*
Control	Count	9	303	312
	Percent	*2.9%*	*97.1%*	*100.0%*
Total	Count	43	688	731
	Percent	*5.9%*	*94.1%*	*100%*

*X^2 (1, N=731) = 8.84, $p = 0.003$

Control group. While we cannot report the majors that enrolled students pursued, the vast majority of students at WPI do pursue majors in the STEM disciplines. For example, in 2016-17, 96% of undergraduate women were working toward degrees in the STEM fields.

Discussion

We considered, and subsequently rejected, the possibility that differential admissions practices or special consideration for Reach alumnae might explain these results. The WPI Admissions Office does not use any special recruitment or promotion efforts for Reach alumnae. Moreover, Camp Reach staff do not reach out to alumnae to encourage them to apply. WPI considers candidates for admission based on a holistic review process similar to many institutions of higher education. All applicants must meet the minimum requirements specified by the university. Applicants are then reviewed based on a number of factors including strength of curriculum, grades, letters of recommendation, test scores or optional flexpath, co-curricular activities, teamwork, and demonstrated interest in the institution. Attending a summer program would count as demonstrated interest in the institution; however, the weighting attributed to this would not be enough to significantly affect an admissions decision.

The primary limitation of this study is that it does not provide insight into the reasons behind the more positive admissions outcomes for the Reach group. We plan to extend this study to explore those reasons. For now, we can suggest some possibilities. An interesting ancillary finding is that the rate at which women in the Control group and in the Reach group, especially, have applied for undergraduate admission to WPI has steadily increased in recent years, as shown in Figure 1. Overall applicants to WPI have increased over the same period, which could be the primary contributing factor to this trend. However, another contributing factor behind stronger admissions outcomes in recent years could be a larger number of “touch points” between the institution and those Camp Reach applicants who ultimately apply to WPI. Touch points could include participation in additional summer and academic year enrichment programs in the middle school and high school years, attendance at Camp Reach reunions, and returning to Camp Reach as a staff member during the high school years. Beginning in 2009, WPI began increasing the number of so-called “pipeline programs,” particularly for students in the middle school and early high school years. Table 5 summarizes the continuum of programs available for students of various ages, and the year those programs were introduced. More frequent interaction with the university’s people and programs could engender feelings of connection, community, or comfort. In addition, ongoing engagement with science and engineering practices outside of the formal school curriculum and continued access to role models could contribute to more likelihood of applying to a STEM-intensive institution such as WPI.

One component of future work will be to examine the number of touch points for subjects in this study sample, both in the Reach group and in the Control group. Another element of future work is likely to be interviews with Camp Reach alumnae who chose to come to WPI. Such qualitative data are likely to enrich our understanding of STEM education pathways for young women.

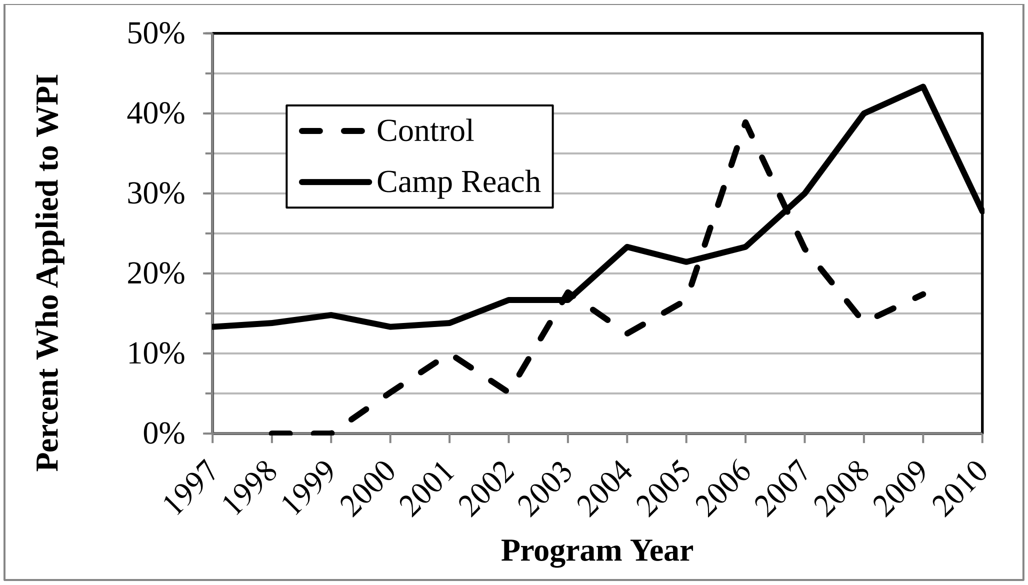

Figure 1. Application rate by program year for the Reach and Control groups

Conclusion

This study adds to the body of literature on the benefits of STEM outreach to middle school girls by showing a direct undergraduate admissions benefit of a two-week residential program for rising 7th graders. The program offers continued opportunities for girls to engage with cohort peers, role models, and university programs in the subsequent middle school and high school years. The study is noteworthy for its experimental design that controls for self-selection and other forms of application bias. We hope the findings will be helpful to universities that are weighing the costs and benefits of middle school STEM outreach programs for girls.

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Table 5. Development of Pipeline Programs at WPI*

Program	Time	Year Founded	Age	Audience
Frontiers	Summer	1985	High School	Boys and Girls
Camp Reach	Summer	1997	Middle School	Girls only
Launch	Summer	2006	High School	Boys and Girls
Tech Girls After School Program	Academic Year	2008	Middle School	Girls only
Crime Scene Science Summer Program	Summer	2009	Middle School	Boys and Girls
iBio-Bioengineering Program	Summer	2009	Middle School	Girls only
Video Game Design	Summer	2009	Middle School	Boys and Girls
STEM Saturdays	Academic Year	2010	Middle School	Girls, Boys and Parents
Middle School Tours	Academic Year	2010	Middle School	Boys and Girls
Advance Robotics	Summer	2010	Middle School	Boys and Girls
Junior Robotics	Summer	2010	Middle School	Boys and Girls
Leadership Academy for Young Women	Summer	2010	Middle and High School	Girls only
Touch Tomorrow	Academic Year	2012	All	All
Geek is Glam with Girl Scouts	Academic Year	2013	Middle and High School	Girls only
Women in Science	Summer	2013	Middle School	Girls only
Physicspalooza	Summer	2013	Middle School	Boys and Girls

* Does not include programs that operated in earlier years but no longer continue.

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