A Comparison of Changes in Science Interest and Identity and 21st Century Learning Skills in a Mixed-Gender and Single-Gender Robotics Program for Elementary/ Middle School Youth

Ms. Suzanne Sontgerath, Worcester Polytechnic Institute

Sontgerath holds a B.S. in Mechanical Engineering from Worcester Polytechnic Institute and an M.Ed. from Worcester State University. She is currently the Director of Pre-collegiate Outreach Programs at Worcester Polytechnic Institute. Sontgerath supervises K-12 STEM outreach programs at WPI including Camp Reach and several other summer and academic year programs for students and parents.

Mrs. Ryan Nicole Meadows, Worcester Polytechnic Institute

Ryan Meadows holds a B.S. in Mathematics and Business from Fitchburg State University and an M.A. in Teaching from Sacred Heart University. She is currently the Associate Director of Pre-collegiate Outreach Programs at Worcester Polytechnic Institute. Meadows works with K-12 S STEM outreach programs during the summer and academic year.
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Women’s historical underrepresentation in Science, Technology, Engineering and Math (STEM) is evident at all junctures of the pipeline from elementary education to industry. Providing students with STEM experiences is one method of alleviating this gender imbalance and building 21st Century Skills. At Worcester Polytechnic Institute (WPI), outreach programs in robotics tend to be primarily boys. Based on WPI’s success in offering single-gender programming to build self-efficacy, the university added a section of robotics for girls only. To measure outcomes, WPI collaborated with the PEAR Institute: Partnerships in Education and Resilience at Harvard Medical School and McLean Hospital. Participants in four robotics sections (N=95, 28% girls) were surveyed using a validated reflective assessment at the end of the program. Three sections were mixed-gender and one section was single-gender. Two different female STEM educators taught four sections. The assessment measured science interest, science identity and the four 21st Century Learning Skills; critical thinking, perseverance, relationships with peers and relationships with adults. Participants in the robotics programs experienced statistically significantly gains in science interest and identity. There were no statistically significant differences between the genders or in the single gender section. For the 21st Century Skills, participants had gains across all skills. Females reported a significantly higher increase than males on the relationships with peers’ skill with the percentage of change greater for the girls’ only section. Participants at WPI had significantly higher gains in science interest than the PEAR national database of informal science programs. These results indicate that informal, project-based, collaborative science programs have the potential to affect relationships with adults and peers. Additionally, critical thinking and perseverance are impacted through project-based learning. While not reaching a level of statistical significance, outcomes for the participants in a single gender environment resulted in outcomes that were more positive for girls. These results make a case for further research on single gender informal science experiences.

Introduction

Since the early 1990s, researchers have been exploring the reasons for the gender disparity in STEM (Science, Technology, Engineering and Math) and developing interventions designed to increase the numbers of women entering STEM fields. Experts agree that a diverse STEM workforce leads to global competitiveness and better economic outcomes for all involved [1]. In a 2009 study of for-profit corporations, Herring found that gender diversity in the workforce could be connected to greater sales, more customer acquisitions and ultimately larger profits [2]. Additionally, the Bureau of Labor Statistics (BLS) projects growth rates for STEM occupations
of about 13% between 2012 and 2022, which is faster than average for all occupations. Workers in STEM occupations earn a median annual wage that is more than double the median wage for all other workers [3]. In order to guarantee the same economic advantage for all of the population, we must ensure that women are entering and persisting in STEM fields at similar rates to men. While the United States has a balanced college-educated workforce made up of more than 50% women, the science and engineering workforce is comprised of only 29% women. The proportions of women in engineering (15%), physical sciences (31%) and computer sciences and mathematics (25%) are particularly low [4].

One method for developing workforce ready STEM professionals of both genders is to develop 21st Century Learning Skills. These skills include collaboration, communication, social/cultural skills, creativity, critical thinking, and problem solving [5-7]. These skills are more difficult to teach than technical content and more difficult to measure than academic performance. Informal educational settings can provide the right environment for such skills through project based learning (PBL). In a PBL environment, students learn accountability, independence and discipline [6].

Many research studies indicate that girls’ interest in STEM disciplines may wane during the middle school years [8]. However, attendance WPI’s summer robotics programs over the last several years indicates that girls may turn away from STEM as early as grade 5. WPI has offered robotics programs for elementary and middle school students since 2008. The number of girls registering for the robotics programs has hovered between 10% and 20% women. The total number of girls in all of our summer STEM offerings is significantly higher, usually between 35-40%. The platform used for the summer robotics program is Lego Mindstorms®. Traditionally in the United States, Lego® and robots are masculine associated toys. Therefore, the possibility exists that girls do not have as much experience building and playing with these toys. Some research indicates peer groups for women and girls can affect their participation in STEM. Values that are supported in peer groups might be in conflict with values associated with STEM. In other words, if it is not “cool” to play with Legos® as an elementary or middle school girl, participation in a robotics program might also be rejected [9]. The authors suspect that girls (and in some cases their parents) might have low self-efficacy as it relates to Lego® building and robotics experience. Because of the lower self-efficacy, the girls do not register for the robotics programs. Based on WPI’s success in offering single-gender programming in other areas to build self-efficacy, the university added a section of robotics for girls only [10, 11].

The authors surveyed 95 participants across four sections (including the single gender section) of a robotics summer program using a validated reflective assessment [12-15]. The research questions the authors hoped to answer were a) Does an informal STEM environment lead to increased science interest, science identity and improved 21st Century skills? b) Is there a difference in outcomes for girls in a mixed gender environment versus an all-girls environment?
LITERATURE REVIEW

In order to develop a contextual framework for the research, the authors conducted a review of the current literature. Areas of interest included: the theoretical pros and cons of single-sex learning environments, the efficacy of informal STEM outreach programs in increasing STEM interest or STEM identity, and the importance of the development of 21st Century learning skills in today’s educational paradigm.

Single-gender education pros/cons

The literature related to the effect of single-gender education is conflicting. While many of the studies show some type of positive outcome for women in a single-gender setting, researchers raise many questions around self-selection bias in the study designs. A meta-analysis [16] reviewed 184 separate studies. The researchers divided the studies into true empirical research with a controlled experimental design and those with an uncontrolled design. They found that controlled studies demonstrated a slight positive correlation for women in relationship to math performance and science performance, but these results did not reach a statistically significant enough level to make an argument in favor of single-sex education at a public-school level. Others have found that there are positive outcomes associated with single-gender education setting for women including better performance academically, a decrease in stereotype threat because gender is less salient in a single sex setting, and an increase in confidence in ability [17-20]. The results of a controlled study in the “masculine” subject area of physics resulted in better physics self-concept of ability for girls in the single-sex classroom than their peers in co-educational classrooms [20]. Since robotics is also a “masculine” subject, it is likely that similar results might occur. In fact, Milto, Rogers & Portsmore, found that girls in an undergraduate robotics course have less confidence in their ability when it comes to robotics and don’t speak up in mixed-gender groups [21].

In summary, single-sex educational settings may help to overcome gender stereotypes and increase performance in math and science, but confidence in research outcomes is mixed.

Efficacy of Informal Outreach Programs to Increase Interest in STEM

Based on some of the research that suggests that single sex education can lead to positive outcomes, many single gender informal outreach interventions have been developed. Participation in out of school time (OST) informal learning opportunities can lead to an increase STEM identity, interest and confidence. Much of the body of research focuses on interventions for middle school girls as opposed to high school or elementary school girls or boys of any grade level [10, 11, 22-24]. In their study of the impact of the National Science Foundation’s Program
for Women and Girls, [25] found evidence that summer camps were “successful in achieving positive change” for girls in STEM. A meta-analysis of the effect of 19 OST programs on student interest in STEM suggest that these programs do have an effect on student interest in STEM. The type of program and length of the program were not statistically significant moderators of student interest in STEM, but programs with an academic and social component had a larger effect. In this study, gender was not a factor in level of interest (Young, Ortiz, & Young, 2017). In a literature review of a variety (4) of engineering programs designed to encourage girls, authors Sinkele and Muping (2011), note that most of the programs do support the hypothesis that participation in an engineering pre-college programs does increase the likelihood of women to enter engineering. The review of a robotics program by Weinberg, et al. (2007) as reported in this article indicated that after 7 weeks of participation, girls had a higher interest in engineering and a more positive attitude towards engineering. Other programs have struggled to define positive outcomes especially in the long term. [26] evaluated a 2-week residential science enrichment program for high-achieving eighth-grade girls. Outcomes were measured 4 years after the program, for both program participants and applicants who did not attend. The study found no effect of program participation on a variety of outcomes, including science self-concept and interest and plans for a college science major. In previous research by this author on a two-week, engineering camp for girls’ longitudinal research did indicate that girls enter STEM at higher rates than control. They also matriculated to the institution at higher rates [10, 11].

Overall, the trend in the research for short-term outcomes seems to be towards increased interest and identity through OST interventions. The longitudinal effect of these outcomes is more inconsistent.

**Background about Summer Programs at WPI**

Since 2008, WPI has been offering a Junior Robotics Program in the summer months. The program uses the Lego Mindstorms® platform and the competition design of the FIRST Lego League. These week-long sections of the program are offered for a maximum of 30 students. There is one classroom instructor, two undergraduate program assistants and 4 high school mentors. The hours of instruction are from 9:00 AM to 4:00 PM each day with a one-hour break for lunch. During the course of the week, the students in grades 4-6 work in teams of three using one Lego Mindstorms® kit to build and program a competitive robot. Students participate in a project based learning environment where there is an emphasis on collaboration, communication and critical thinking. At the end of the one-week session, there is a team competition to determine the most successful robot. Awards are also given for teamwork, communication and sportsmanship.

Historically, the programs have been population by a majority of boys. Some sections of robotics only had one girl in a class of 30 students. As the popularity of WPI summer programs has grown, those numbers have increased slightly. In the last three years (2015-2017), the gender breakdown for women in the robotics program has been 24%, 13% and 29% respectively. The larger number in 2017 is due in part to the addition of a girls’ only robotics section. As noted above, we added this section with the hope of
attracting more girls to the robotics programs. In the inaugural year of the girls’ only section, we were able to fill 17 out of 30 available seats. Registration for the programs is on-line and operates on a first come first served basis. Parents register their child for the program and pay immediately. Tuition assistance is available for families with demonstrated financial need. WPI did not promote the girls-only robotics section any differently than any of the other summer programs.

METHODS

Two research questions that were of interest to the authors:

• Does an informal STEM environment lead to increased science interest, science identity and improved 21st Century skills (i.e., critical thinking, perseverance, relationships with peers, and relationships with adults)?
• Is there a difference in outcomes for girls in a mixed-gender environment versus an all-girls’ environment?

Sample

The sample consisted of ninety-five (N=95) students in grades 4-7 in four sections of the robotics program. Three of the sections were mixed-gender and the forth section was a single-gender section. The gender breakdown of the all the students was 69% male and 28% female with 3% of students who preferred not to answer. In the mixed-gender groups, the breakdown was 76% male and 14% female. Although race was not a factor in the data analysis, 23% of the sample population was Caucasian. In terms of grade level, there were two fourth grade students, 57 fifth grade students, 33 sixth grade students and 5 seventh grade students. Two different female STEM educators taught four sections. One instructor (instructor A) had previous experience teaching the robotics program and taught the mixed-gender programs. The other instructor (instructor B) was a new instructor and taught the single-gender section. In the previous summer, the instructor B had completed a teacher professional development program at WPI to learn the curriculum. Additionally, instructor B shadowed instructor A for two weeks before teaching the program herself. Therefore, curriculum in both sessions was similar.

Data Collection and Analysis

Data was collected using the Common Instrument©, the Holistic Student Assessment© and the Science Identity (SCIID) developed by The PEAR Institute: Partnerships in Education and Resilience. Permission to use these instruments was obtained from The PEAR Institute at Harvard Medical School and McLean Hospital. The Common Instrument© measures students’ interest and engagement towards STEM. The Holistic Student Assessment© measures four socio/emotional learning factors/21st Century skills: Critical Thinking, Perseverance, Relationships with Adults and Relationships with Peers. The Science Identity scale measures students’ perceptions about themselves as a “Science Person” (recognition) as well as how able they feel they are to do Science (capability). [12-15]
The researchers administered the survey to youth in the Robotics program on the last afternoon of each section at approximately the same time. Researchers read the participation disclaimer aloud to the students and confirmed understanding before surveying commenced. Surveys were anonymous. Researchers obtained approval to conduct this research from the WPI Institutional Review Board and parental consent for participant of minors.

Authors submitted the survey data to the external evaluator PEAR for analysis.

RESULTS

Overall student gains in 21st Century Skills and Science Interest/Identity

Participants (Grades 5-7) in the WPI robotics program reported statistically significant gains (p<0.001) across all four 21st Century Skills subscales: Critical Thinking, Perseverance, Relationships with adults and Relationships with Peers (Figure 1). Participants also reported statistically significant gains in Science Interest (p<0.001), and in Science Identity (p<0.01).

Figure 1: 21st Century Skills: Overall Averages (combining all 4 sections)

<table>
<thead>
<tr>
<th>21st Century Skills: Average Retrospective Responses Overall</th>
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<tbody>
<tr>
<td>Critical Thinking</td>
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<tr>
<td>Much More</td>
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<tr>
<td>More</td>
</tr>
<tr>
<td>About the Same</td>
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<td>Less</td>
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<td>Much Less</td>
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Gender differences

There were no statistically significant differences in results by gender on the majority of the subscales with the exception of the item: Relationships with Peers in the 21st Century learning skills. On this subscale, all girls, regardless of which section they were in, reported a significantly higher increase than boys did (p<0.05). There were no statistically significant differences between responses by gender on the remaining three 21st Century Skills subscales (Figure 2).

Figure 2: 21st Century Skills: Average Retrospective Responses by Gender
The analyses of the average responses from three distinct groups: Girls belonging to the single-gender cohort, girls that were in co-ed programs, and boys that were in co-ed programs on measures of Critical Thinking, Perseverance, Relationships with Adults, and Relationships with Peers revealed no statistically significant difference in mean scores (p>0.05), as seen in Figure 3. However, one hundred percent of girls in the single gender cohort reported gains in STEM identity, Critical Thinking, Perseverance and Relationships with Peers. The all-girls cohort was the only group to report gains for 100% of the group in any subscale item. There was also a significant correlation between gains in science interest and gains in 21st Century Skills. Finally, when compared with national norms through the PEAR database, WPI robotics students demonstrated significantly higher gains (p<0.05) but also demonstrated statistically fewer gain in Relationships with Adults (p <0.05) when compared with national norms.

**DISCUSSION/CONCLUSION**

The results answer the research question as to whether informal STEM educational settings can lead to increased science interest, science identity and improved 21st Century skills. Overall, students participating in the WPI robotics programs reported statistically significant gains in Science Interest and Identity and on all four of the 21st Century Skills. These gains indicate that
an informal learning environment with a project-based curriculum focused on teamwork can lead to the further development of interest in STEM disciplines, as well as the development of the professional skills necessary to be successful in those disciplines.

In terms of support for an all-girls learning environment versus a mixed-gender environment, there are no statistically significant results in this study to indicate that a single gender environment improves outcomes. However, the authors are encouraged that 100% of the girls in the single gender cohort did experience gains in a majority of the subscales. This indicates that the cohort was a positive experience for those involved. These results could be interesting for other educators or researchers considering a single gender model for outreach program design.

There are two limitations in this study. The first is self-selection bias. Parents are allowed to register their children to the section of their choice so there is no random assignment to the single gender versus the mixed-gender sections. Therefore, girls choosing the single-gender environment may have been pre-disposed to feeling more comfortable in such an environment. Further research on these programs should include an experimental design using random assignment to the co-ed and single sex cohorts in order to provide more methodologically sound results. Due to availability of the program educators, we were not able to have the same educator teach in all four cohorts. Both were female secondary school educators; however one had experience teaching the robotics program and other did not. The experienced teacher taught the mixed-gender cohorts and the new teacher taught the girls only cohort. Future studies could be conducted using the same educator for all four cohorts.

Further research directions could include an analysis of the gender make-up of the teams in a mixed-gender environment to answer the question: Do girls perform better on mixed teams or in single-gender teams? In addition, qualitative assessment might be valuable in order to capture the nuances that quantitative surveys do not always pick up when the sample size is smaller. Another potential research area would be to explore changing the robotics competition to a more gender-neutral competition that involves humanoid or animal robots instead of vehicles [27]. The authors would also like to explore the specific program elements that lead to the gains in science interest and identity and 21st Century Skills.

REFERENCES


