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Middle school robotics camp: Stem skills findings among girls and boys

Niyati Kottury[1], Nirav Kottury[2], John Leddo[3]
[1] Briar Woods High School, Ashburn, Virginia, United States
[2] Academies of Loudoun, Ashburn, Virginia United States
[3] Yale University, New Haven, Connecticut, United States

Abstract
Previous research on the several robotic camps was published in discovering the common factors contributing to the lower participation of girls and minorities in embracing STEM fields. There is a lot of research published in the factors that drive the participation of girls in STEM events, such as robotics camps, and affect their performance in the same activities compared to boys, along with the instruction model that supports a controlled environment for both boys and girls. A pilot study of 17 middle school students (6 girls and 11 boys) between grades 6 and 8 was conducted to determine the factors that drive registration for the event, and the findings were gathered via qualitative and quantitative assessments over a period of 10 weeks. The robotics camp was conducted with Parallax Boe-Bots (robots) that use a non-GUI based programming language called PBASIC, which teaches the students mechanical assembly with hardware and electrical components, software coding skills, and system level troubleshooting. Results showed that in a learning environment, contrary to a competitive environment, girls performed at the same level as boys in the mechanical assembly, software coding (which takes into account basic coding), advanced programming skills, and system level troubleshooting. A learning environment with a lower student to coach ratio (coach: student - 1:2) helped students adapt and learn simple to complex tasks seamlessly. Students and parents played an equally important role in having Students sign up for the robotics camp and see value in pursuing a STEM career.

Keywords: stem, gender differences, boys, girls, aptitude, skill, robotics, stem camp

Introduction

By 2025, the number of jobs in STEM fields is predicted to be 3.5 million. Women represent 51% of the workforce, but they represent less than 25% in STEM fields. With 50% of the current workforce in STEM fields planning to retire by 2025, it is estimated that 2 million jobs will go unfilled (Deloitte Consulting, Nov. 2018) [32]. 15% of the engineers were predicted to be women, and women contribute to 25% approximately of math and computer majors in the US (National Science Board, 2014) [26]. Between 2000 and 2009, the percentage of college-educated female graduates increased from 46% to 49%, but the percentage of women in STEM fields remained constant (Beede *et al*, 2011) [2]. Research indicates that women choose not to pursue careers in STEM fields due to lack of interest; however, more evidence confirms that women are socialized away from STEM fields. (Johnson A.C, 2007) [18]

To close the STEM gap of two million by 2025, it will require as many students as possible to be aware of the shortage of students proficient in STEM skills from elementary to high schools and actively recruiting women and minorities in developing interest in STEM fields. To increase the number of women in STEM disciplines, it is important to begin training female students much earlier than college (Corbett & Hill, 2015; Markert, 1996; Metz, 2007; Sullivan & Bers, 2016) [31].

The common factors that can be attributed to the lower participation of women in STEM are:

- **Gender Stereotypes**: Teachers and parents often underestimate girls' ability to perform well in STEM related fields. With more presentation of men in STEM fields, teachers and parents tend to think STEM fields Are primarily for men only. (Metz, 2007; Steele, 1997) [24]
- **Culture:** With fewer women participating in the STEM courses at colleges and professional careers in STEM, female cultures at colleges and workplaces tend to become more conducive towards males in the case of STEM professions. (Guiso, L., Monte, F., Sapienza, P., & Zingales, L., 2008) [15]
- **Lack of Role Models:** With fewer women at colleges and at work, limited examples of female scientists and engineers tend to dissuade girls in pursuing STEM education and careers. (Marx, D. M., & Roman, J. S., 2002) [22]
- **Math Anxiety**: Female teachers who teach math tend to pass on their math anxieties to the students. Male teachers who do not show math anxiety further reinforce the idea that women were not good in math.(Beilock, S. L., Gunderson, E. A., Ramirez, G., & Levine, S. C., 2010) [3]

Teaching robotics from an early age (elementary and middle school) serves to increase interest for girls and prepares them with the skills required for robotics and computer science, serving to break ingrained stereotypes they may experience (Metz, 2007; Steele, 1997) [24]. Also, robotics offers an engaging way to learn foundational programming concepts and introduces children to important ideas about many of the everyday objects with which they interact (Bers, 2008) [5]. Robotics helps children develop fine motor skills and hand-eye coordination while engaging in a collaborative environment (Lee, Sullivan, & Bers, 2019) [4].

Further research suggests that promoting an atmosphere of cooperation and support in a class environment increases the likelihood of girls embracing math and science (Perna, Lundy-Wagner, Drezner, Gasman, Yoon, Bose, & Gary, 2008) [27]. A variety of neural and chemical reasons confirm why boys tend to be more inclined towards competitive events than girls, and how competitive environments help boys improve in performance but not girls (Gurian, 1996; Gneezy and Rustichini 2004) [14, 16]. This further confirms that girls tend to thrive in a learning and collaborative environment.

Female role models in students learning can help many female students majoring in engineering and STEM disciplines (Amelink & Creamer, 2010) [1]. Per Sullivan and Bers (2018) [6], having a female robotic instructor leads to almost no difference in performance - girls performed at the same level as boys on programming tasks. Per Wang & Degol (2016) [33], expectancy-value theory asserts that women are less likely to pursue math-intensive fields due to their relatively lower math and science expectancies and values in comparison with men, whereas mindset theory suggests that females are more susceptible to reduced math performance in the context of endorsing a fixed mindset in math ability. Research has shown that women often have less experiences with tinkering during their childhoods compared to men (McIlwee & Robinson, 1992) [23]. By providing female students with opportunities to build, play, and explore with construction and engineering toys, as well as developmentally appropriate technologies throughout their early childhoods, it is possible that they will be more experienced and confident in these domains by the time they reach late elementary and middle school.

In recent years, there has been a steady increase in the number of girls participating in robotics competitions such as VEX robotics and LEGO competitions. Programs such as VEX Robotics increased female participation from 23% in 2016 to 37% in 2018 (Edsurge, Sept. 2019) [29]. In the state of Georgia, the number of girls participating in LEGO competitions is around 30% (ASEE annual conference and exposition, June 2013) [25]. With female participation in STEM fields still less than 50%, this paper focuses on answering the following research questions as part of the robotics camp that was conducted with 6 middle school girls and 11 middle school boys over a period of ten weeks lasting for 2.5 hours per session.

Research Questions

1. What were the underlying factors that drive the registration for events like robotics camps - including the design and content of the flyer for advertising?
2. Are there any notable patterns between girls or boys that emerged on the usage of the laptop before and during the camp?
3. What were some key observations in the class between the students and coaches, and the location of seating and participation among girls and boys, including their willingness to share in front of the class?
4. Are girls better than boys in certain skills such as robot construction, software coding in PBASIC environment, hardware assembly, code syntax articulation, systems integration, and trouble shooting at the mechanical, electrical, coding, and system levels?
5. Are there key observations from the robot parade in showcasing student's skills with family members as audience?

Materials and methods

Participants

A total of 17 students, with 6 girls and 11 boys participated in the robotics camp for 10 weeks. The camp met every Friday for 2.5 hours each session, except for holidays and unplanned school closures due to events such as snow. The students were recruited through a Google Form link that was written on the brightly-colored flyers posted on the club activities bulletin board in their school. The flyer was also posted under the middle school activities page and the school's social media. The flyer was sent to all the middle school parents' email addresses, allowing them to sign up on behalf of the students - the schooling system prohibits sending mass emails directly to the students' school accounts.

To have students sign-up for STEM activities such as robotics camps, students and parents both play a large role; the majority (95%) of the registration comes through the parents. The parents' awareness of STEM disciplines and seeing value in STEM skills drives the registration for events.

Robot Used

The robot that was used for the training is called the Boe-Bot Robot- USB manufactured and distributed by Parallax Inc (www.parallax.com). Boe-Bot was chosen by design, taking into account factors such as the complexity of the assembly that is required, non-GUI based programming, and electrical circuits involving printed circuit boards (PCB), sensors, resistors, and wires etc. requiring detailed work. Boe-Bot assembly requires the usage of mechanical components such as small screws, nuts, a screwdriver, a ball, and sockets. The non-GUI based programming language PBASIC was used to gather information on how the students react and adapt when they learn to code in an environment that looks very similar to advanced programming languages such as JAVA, Python, etc. Students were required to use electrical components such as resistors, wires, breadboards, and sensors, etc. to complete their electrical circuits before downloading the code that was written in the PBASIC language.

Procedure

As part of the teaching curriculum, students at this middle school used school-provided laptops. After the registration, students were sent emails outlining the steps that need to be followed in downloading the software and drivers on to their personal laptops. This step was required to be able to write code on the laptop, and download the code onto a robot. All the students confirmed during their first session that they completed the task at home as part of the pre-camp activities, and when they ran into issues, they worked with their parent(s) or older adults to complete the task.

With laptops being widely used at school and at the students' homes, as well as help from the adults when needed, students (girls and boys) did not exhibit any difficulty completing pre-camp software and driver download.

The camp was conducted right after school, allowing students to stay after their classes (3:30PM) and be picked up by their parents after the camp. Almost all of the sessions in the camp lasted for 2.5 hours. Students were dismissed early if they accomplished what was required for each session sooner. Students were not given homework and anybody who was absent in a class worked with their team members in the following class to catch up with the work that was missed. For all the students, laptops were widely used as part of their school curriculum.

Students were seated in a typical lab-type classroom setting where three to four students sat together at a table that was shared between students. Students who knew each other ended up sitting together more than students who did not know each other. The coach to student ratio was maintained at 1:2 in all sessions of the camp. There were 4 female coaches and 4 male coaches for each session of the camp. There were 3 master coaches (one master coach teaching 3-4 sessions) who would go over the material for each session in a PowerPoint presentation with hands-on exercises.

The coaches who were selected for the camp were professional adults who did not have formal teaching experience. They were trained on the material that was planned to be used at the camp with the same power point slides that were used during the training. They were also given a couple of robots (one robot for 2 coaches) allowing them to actually follow the course packet and go through the training by themselves as the student would go through during the camp. Training of the coaches was conducted by the master coach. Once the training was complete, the master coach requested two additional volunteers who demonstrated proficiency with the course packet and hands-on exercises to join as additional master coaches.

In each of the sessions, there was a quick overview of what was taught the prior week with a quick verbal quiz, allowing students to recollect what was learned and share their understanding with the class. Students were asked by the master coach and were welcome to stand up in front of the class and share their knowledge if they wanted to. Students were encouraged to participate during the review sessions, and they were given partial credit even if students did not answer all elements of the questions correctly. Following the overview, the master coach quickly went over a couple of slides about the assembly of the robot, command syntax that was planned to be used for the day and their common usage in life, and the functions of the electrical components that would be used and the governing engineering principles explained in a simplified form. The students learned about voltage, resistance, currents, diodes, LEDs, breadboards, transistors, printed circuit boards, speakers, microphones, sensors, transmitters/receivers, motors, continuous vs standard, tuning of motors, settings on the motor (full speed, half speed etc) logical block/routines, memory, input/output ports, and software syntax involving start, stop/pause, duration, pseudo code, do loop, for loop, and subroutines.

Once the students were introduced to the concepts that they would be working on, they were given hands-on exercises allowing them to work on what was learned. For each exercise, coaches were around students monitoring them through all the activities that were to be completed, answering questions that the students had, and helped with the steps that were required to complete the activity for the class if needed. During exercises, students did not need to have an answer from the master coach; they could call or raise their hands for any nearby coaches. If the students completed the exercises early, they get to go home sooner as a positive reinforcement. Each of the sessions ended with a round of applause by students for themselves since they accomplished what was expected of them; they were steadily making progress for the celebration of the camp that culminated with the robotic parade where students got to showcase their robot skills and decoration of their robot.

For the robot to make movements per the design, students were required to perform the mechanical assembly, electrical assembly, and software coding correctly. Students were required to download the code from their laptop to the robot via USB controller. If the students ran into issues, they were coached in isolating the problem to mechanical, electrical, or communication issues. This exercise not only helped to troubleshoot at the individual module level but also at the systems level.

Notes were kept by the coaches and the master coach during each session on how students mastered the content, their issues, and how they completed the tasks required for each session. Some measures that were used during the camp were referring to the content while coach/master coach answering their question, successfully using mechanical wrenches and screwdrivers in fastening screws/nuts, correctly orienting the electrical polarities and color coding per the instructions that were provided, correcting syntax errors by referring to the notes that were provided when they run into SW errors, students approach (methodical vs scattered) on troubleshooting problems - Hardware, Software or systems. Based on the measures, the student's skill level was assessed both qualitatively and quantitatively at the end of each session by the coaches and master coaches.

Results and Discussion

Research Question 1: What were the underlying factors that drive the registration for events like robotics camps - including the design and content of the flyer for advertising? It was noticed that more than 95% of the registration came through the parents signing up their kids for the robotics camp. The event had so much popularity that the registration filled up in a couple of hours. During the first session, students were asked "What prompted you to sign up for the robotics camp?", and almost all of the students (90%) responded that they signed up because coding is a skill that is required for future jobs. They also responded that their parents thought it is a good skill to have (95%). 20% of the students (boys and girls) responded that they signed up because it is fun to program a robot. All the students shared that they also joined that robotics camp since there will be no homework required, and at the end of the robot parade they get to keep the robot as a bonus.

Research Question 2

Are there any notable patterns between girls or boys that emerged on the usage of the laptop before and during the camp? The laptops were a mode of instruction at the middle school, and students were very well versed in using the laptop at school and also at home. 100% of the students mentioned that they had a personal laptop at home. Both girls and boys were very comfortable in using the laptop as part of pre-camp activities and also during the 10 week camp. 100% of the students (girls and boys) confirmed that they ran into some issues in downloading the software and those issues were successfully overcome with the help of their parents.

Research Question 3: What were some key observations in the class between the students and coaches, and the location of seating and participation among girls and boys, including their willingness to share in front of the class?

During the first session, students were welcomed to sit wherever they wanted in the class. Most of the students who were friends from the same class or neighborhood sat together in groups of 3 to 4. Girls chose to sit together in the back benches together in a group. Only one girl chose to sit with the boys as a teammate in the class. As part of the review session (open book) that included verbal quizzes in each session, the students were asked to answer the questions that were posed. Both boys and girls did not have any difficulty in recalling the material that was taught. Boys were more likely to raise their hands to volunteer and share their understanding. This behavior was noticed across all 10 weeks of training with 80% of the boys raising their hands each time a question was asked but only 50% of the girls. The difference of 30% is noteworthy with girls not wanting to volunteer to answer the questions. However, when answering questions, boys gave the correct answer only 60% of the time, whereas girls gave the correct answer 80% of the time. This suggests that girls are more likely than boys to answer questions only when they feel confident of knowing the right answer. When given an opportunity to present at the podium and share their understanding, only 3 of 6 girls wanted to do so versus 9 or 11 boys wanting to present. 100% of the time, girls were willing to share their answers if they were allowed to answer questions right from their seat.

Research Question 4: Are girls better than boys in certain skills such as robot construction, software coding in PBASIC environment, hardware assembly, code syntax articulation, systems integration, and trouble shooting at the mechanical, electrical, coding, and system levels?

4 out of 6 (66.6%) girls did not have any difficulty in completing the tasks that were given to them with little to no help from the coaches. The girls followed the instructions that were reviewed during the sessions and followed the steps that were provided to them in the form of hand-outs. 2 of 6 girls (33.3%) needed some guidance from the coches in completing the tasks. With guidance, they were able to complete the tasks at hand. When a task was given, boys were able to complete the task faster than the girls. But 7 out of the 11 boys ran into issues with coding errors in executing code and/or had electrical circuits or mechanical components not responding. The girls, on the other hand, followed the instructions that were to them in the packet, and very rarely they had coding errors when they completed the task.

With the distribution of the male or female coaches available at hand to help, girls and boys openly asked for help from a male coach or female coach. When there were coding errors, it appeared that girls felt more comfortable in having a female coach troubleshoot with them, although they were equally open to work with a male coach. This phenomenon could be due to girls seeing female coaches as their role models.

Fig. 1 shows the assembly of the chassis for the robot. The components on the chassis were the mechanical components that were required to use a screwdriver, nuts, pins etc for the assembly.

Fig. 2 shows the complete assembly of the robot that includes the mechanical chassis with a printed circuit board (PCB) mounted on the top.

The Table 1 shows the data that was collected on student performance of 6 girls and 11 boys over a period of 10 weeks. Students were assessed on their ability to perform mechanical assembly, software coding and troubleshooting capabilities - hardware, software and systems level. Student’s skill level was assessed based on a scale of 1 to 10. 1 represented that a student was not able to grasp the instructions that were provided and execute the steps based on the coach's guidance. 10 represented that a student showed complete mastery of the material that was taught and completed the task at hand with no guidance from the coach. An assessment of 8 represented students needing some guidance in understanding the materials that was taught and some guidance in executing the steps. 9 represented students needing some guidance in understanding the materials that were taught or some guidance in executing the steps. Weekly assessment scores were kept by the coaches and they were finalized based on the notes that were kept by the coaches and master coaches.

The Table 2 statistics were collected on the skill level of the girls and boys after completing the exercise on the mechanical assembly. On a scale of 1 to 10, girls demonstrated their average skill level at 8.17 in comparison to the boys at 9.27. A t-test was conducted to compare their skill level, and it was concluded that there is no evidence to reject the null hypothesis (P value>0.05), indicating that the skill level of the boys is similar to the girls on mechanical assembly exercise. An F-test was conducted to compare the variance between girls and boys; Fcal > Fcritical, so the null hypothesis was rejected and indicated that there is a significant difference in the variance of the skill level that was exhibited by girls and boys. Upon reviewing the factors for higher variance among girls via the notes that were gathered during the workshop, it was discovered that three girls had lower scores than the other three girls. Also, girls who scored lower mentioned that they never had an opportunity to work with a screwdriver until robotics camp. This explains the need for extra help with coaches helping them one on one in completing the exercise.

The Table 3 statistics were collected on the skill level of the girls and boys after completing the exercises on the software coding. On a scale of 1 to 10, girls demonstrated their average skill level at 9.33 in comparison to the boys at 8.82. A t-test was conducted to compare their skill level, and it was concluded that there is no evidence to reject the null hypothesis (P value>0.05) - skill level of the boys is similar to the girls on software coding exercises. The F-test was conducted to compare the variance between girls and boys; Fcal < Fcritical, so the null hypothesis was not rejected and concluded that variance among the girls and boys does not exhibit any significant differences. One important aspect that is worth sharing is that girls demonstrated a steady-pace approach during the software coding, helping them to not encounter errors during their code execution. Boys rushed to complete the coding and they mostly had to get help from the coaches in fixing the errors.

The Table 4 statistics were collected on the skill level of the girls and boys after completing the exercises on the troubleshooting skills that require solving issues after downloading error-free code onto the robot and performing the electrical assembly of the printed circuit board. A common issue that was witnessed among girls and boys were both robot wheels running in clockwise direction instead of anti-clockwise direction. Students were given some time to figure if the values in the code or the placement of the motor cables needs to be changed. This can be achieved by changing the values in the code and/or correctly assembling the cables and motors. On a scale of 1 to 10, girls demonstrated their average skill level at 8.50 in comparison to the boys at 8.45. The students' t-test was conducted to compare their skill level, and it was concluded that there is no evidence to reject the null hypothesis (P value>0.05), so the skill level of the boys is similar to the girls' on troubleshooting skills. The F-test was conducted to compare the variance between girls and boys, Fcal < Fcritical, so the null hypothesis was not rejected; this concludes that variance among the girls and boys does not exhibit any significant differences. One important aspect that is worth sharing is that both girls and boys ran into issues with having both the wheels turn clockwise or anticlockwise. Help was provided by the coaches in having girls and boys understand the concept behind changing the values in the code and/or correctly placing the motor cables in accomplishing the goal. After each session of the software code that was written by the students (girls and boys), students were asked to volunteer to explain their code. Although girls were hesitant to stand in front of the class, when provided an opportunity they were able to share the details of their understanding no different than the boys. In some cases, if the students were able to explain how all elements of the syntax correlate, they were given kudos to share with the class and the master coach spent further time in clarifying the details of the syntax.

Research Question 5: Are there key observations from the robot parade in showcasing student's skills with family members as audience?

Fig. 3 shows the students getting ready for the robot parade. For the parade, students (girls/boys) were provided with flags, construction paper, and stickers to decorate the robot. Both girls and boys enjoyed personalizing the work with their favorite colors and sketches on the construction paper. The event culminated with 17 robots lined up one after another and moved around the four corners of the room with their friends and family. Students (girls/boys) were very excited to showcase their work in front of their friends and family. The students said they really liked working on building, programming, and completing the parade, so they felt proud of themselves. Several parents shared that they were very proud of the hard work that their kids had put in and they really enjoyed watching the work that was demonstrated during the robot parade. The results of the data collection showed that girls do learn better in a class environment rather than a competitive environment, as opposed to boys. The girls also were less inclined to share their opinions unless they were sitting right where they were, and girls perform the software and hardware steps slower than boys, but encounter less errors in doing so.

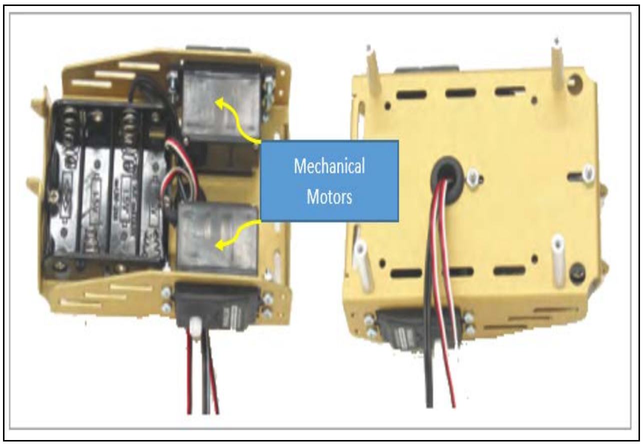

Fig 1: Showing details of mechanical assembly

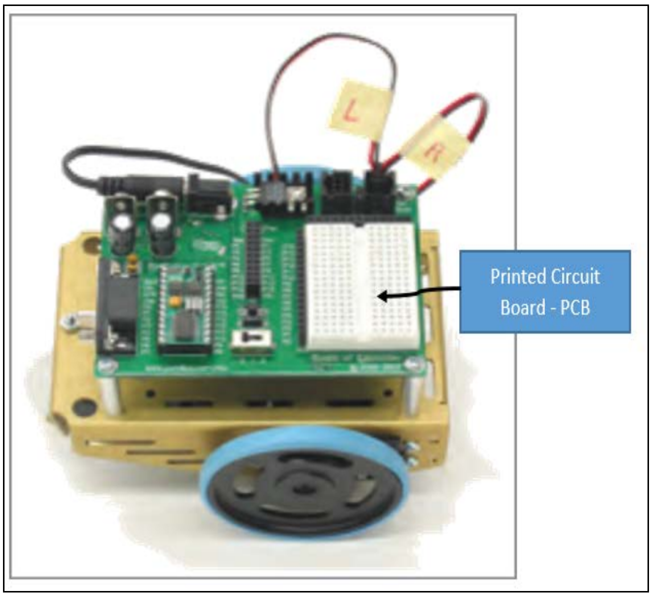

Fig 2: Showing complete robot with printed circuit board

Fig 3: Showing the students performing robot parade

Table 1: Students skill level raw data – Mechanical assembly, Software coding and System level troubleshooting

	Count	Mechanical Assembly	Software(SW) Coding	Trouble Shooting - System Level
Girls	6	8,8,9,9,10,9	10,10,10,9,8,9	8,8,8,9,9,9
Boys	11	10,9,9,10,9, 9,9,9,10,9,9	8,8,8,8 8,8,10,10,10,10,9	8,8,8,8,8,8,9,9,9, 9,9

Table 2: Calculated values for Mechanical Assembly

	Sample Size	Mechanical Assembly				
		Average Score	P_{value}	Variance	F_{cal}	$F_{critical}$
Girls	6	8.17	0.096	1.77	8.10	3.33
Boys	11	9.27		0.22	Reject Null	

Table 3: Calculated values for Software Coding

	Sample Size	Software Coding				
		Average Score	P_{value}	Variance	F_{cal}	$F_{critical}$
Girls	6	9.33	0.27	0.67	1.45	4.74
Boys	11	8.82		0.96	Do Not Reject Null	

Table 4: Calculated values for System level troubleshooting skills

	Sample Size	Troubleshooting Skills				
		Average Score	P_{value}	Variance	F_{cal}	$F_{critical}$
Girls	6	8.50	0.87	0.30	1.1	3.33
Boys	11	8.45		0.27	Do Not Reject Null	

Conclusions

By 2025, it is estimated that 2 million STEM jobs will go unfilled in the United States due to the lack of people with STEM skills (Deloitte Consulting, Nov. 2018)[32], with women representing only 25% of the workforce. Caucasians represent 66.6% of the STEM workforce with 20.6% Asians, 6.0% Hispanics, 4.8% African-Americans and 2% Other (NSF, NSB 2018) [26]. To close the STEM gap, outreach efforts at the fundamental level are required in getting girls and boys from minority communities introduced to the STEM options from middle school. The 10-week robotics camp that was conducted with middle school boys and girls concludes that girls perform comparable to boys in mechanical assembly, software coding skills, and troubleshooting skills. With regards to the mechanical assembly, on average girls performed comparable to boys, although some girls showed lower levels of maturity in the mechanical assembly. Girls with a lack of knowledge on the mechanical assembly easily overcame their difficulties with the help of focused coaching in absorbing the content and completing the tasks at hand. Regardless of sex (girl or boy), students in lower grade levels needed a little more attention from the coaches than the students in higher grade levels.

Instead of conducting a typical robotics competition, having to culminate the event with the celebration of their work in the form of a robotic parade gave the girls and the boys more inclination to participate. This was equally enjoyed by the parents and family attending the robotic parade. Personalization in the form of robot decoration played a big role for both boys and girls in expressing their creativity and showcasing a sense of pride with students, friends, and family.

The set-up of the robotics camp with emphasis on learning rather than competition showed that girls adapt and learn better when they were not required to compete and supported by the coaches for immediate guidance and feedback. Each coach supporting only a limited number of students (Coach to student ratio: 1:2) helps them increase their attention per student and also helps them develop skills even if the students lack skills in completing the task at hand. Although girls felt comfortable obtaining guidance from a male coach or female coach when stuck on the task at hand, having female coaches helps the girls to see them as their role models.

Almost all of the robotic camp registration came from the parents registering the students for the camp. Parents played a significant role in selling the need to have coding skills and convincing their kids that attending the robotics camp will benefit them in the future. This further clarifies that to close the STEM gap, students should not only want to attend the camp, but also the parents should see value in having their kids (girls and boys) attend. There should be a grassroots level effort in having both parents and students (girls and boys) promote and pursue STEM fields. Not giving homework after class seems to be one of the factors that kept the students engaged for a 10-week period training, and having to keep their robot as a gift at the end of the 10 week training kept their motivation to learn and complete tasks at each session. The students were very interested in STEM as we found out in the surveys, and at the end of training when asked if they would be interested in pursuing a STEM career, the students said yes because they were even more interested in stem after attending the camp sessions.

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