Paper ID #20183

Design, Code, Build, Test: Development of an Experiential Learning Summer Engineering and Computer Science Outreach Program for High School Students (Evaluation)

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Abstract

The Science, Technology, Engineering, and Math (STEM) "pipeline" that is imagined to guide students from middle school into successful STEM careers implies a single path. This path often requires students to develop an interest in STEM by middle school, choose particular math and science courses in middle- and high-school, and gain experience and exposure in STEM activities through their high school tenure. While successful for approximately 7% of students who entered 9th grade in 2001, this system has filtered out 93% of the population, including many students who might have had interest and potential to pursue STEM careers. Importantly, this pernicious systemic problem impacts students of color (African American, Hispanic American, American Indian and Alaska Native students) disproportionately. To address this challenge, Access Summer Program to Inspire Recruit and Enrich (ASPIRE) was designed to broaden the participation of students of color and students from economically disadvantaged backgrounds by inspiring and preparing them to pursue degrees in engineering and computing.

ASPIRE is a two-week residential summer outreach program with emphasis on the engineering and technology components of STEM to prepare high-school students with 21st century skills of critical thinking, collaboration, and communication. The program provides students with the confidence needed to enter the dynamic workforce of the future, which requires understanding of basic structure, materials and electrical design and computing. This program is guided by project-based learning, an experiential learning pedagogy that focuses on excitement, engagement, applying the scientific method and engineering process, and making a presentation to demonstrate mastery of these principles. ASPIRE introduces students to the fields of computer science and engineering. Students participate in hands-on group projects centered on the Internet-of-Things. The experiential learning experience provides students exposure to computer programming/coding, computer aided design, laser cutting, and 3D printing. Through ASPIRE, students are able to engage with their peers, form networks, and gain a sense of community. In the past two summers, 41 students have participated in the program. This paper provides details on the design and evaluation of the ASPIRE program.

Introduction

The STEM "pipeline" that is imagined to guide Science Technology Engineering and Math (STEM) students from middle school into successful STEM careers has sprung leaks at essentially every junction. In its most common configuration, it implies a single path that often requires students to develop an interest in STEM by middle school, choose particular math and science courses in middle- and high-school, and gain experience and exposure in STEM activities through their high school tenure [1-4]. While successful for approximately 7% of students who entered 9th grade in 2001, this system has filtered out 93% of the population, including many students who might have had interest and potential to pursue STEM careers [3]. Importantly, this pernicious systemic problem impacts students of color (African American, Hispanic American, American Indian and Alaska Native students) disproportionately. For example, in 2010 students of color represented 31.3% of the nation's population [5], but earned 17.8% of the engineering and science degrees [6]. Looking forward we see that by 2020, almost half of the nation's k-12 school population will be represented by students of color – 28.9% Hispanic, 15% African-American, and 1% American Indian and Alaska Native [7]. Therefore, new approaches need to emerge to attract and engage these students in STEM throughout high school.

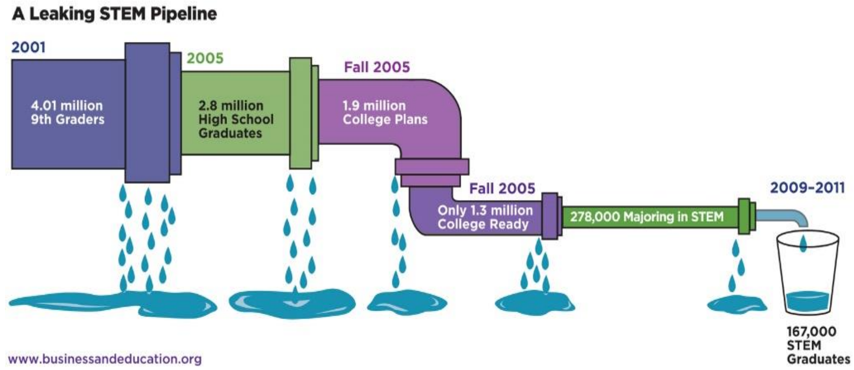


Figure 1. In 2001, more than 4 million 9th graders entered the STEM pipeline. Four years later, only 278,000 high school graduates were pursuing a major in STEM [3]. Ten years after entering high school, only 4% of 9th graders eventually graduated with STEM degrees. African Americans and Latino students yield was between 1-2% for a STEM degree [8].

To address this challenge, Access Summer Program to Inspire Recruit and Enrich (ASPIRE) was designed to broaden the participation of students of color and students from economically disadvantaged backgrounds by inspiring and preparing them to pursue engineering and computing degrees. Research and evaluation of efforts to increase student success in STEM have found that programs that successfully prepare students for STEM careers generally follow the Engagement, Capacity and Continuity Trilogy for Student Success (ECC Trilogy) [3, 9-11]:

- Engagement – Orienting students to STEM, including awareness, interest, and motivation.
- Capacity – Improving skills needed to advance to rigorous STEM and quantitative content.
- Continuity – Through engagement and tracking, students are provided with programmatic opportunities, and guidance to support advancement to and through rigorous STEM content.

Most STEM outreach programs offer a level of engagement. However, raising student awareness and interest is not enough. There is a need for students to acquire 21st century knowledge and skills needed to advance to the rigorous content in the STEM disciplines (*capacity)* and have systems in place to provide students access, support, and guidance *(continuity)*. ASPIRE goes beyond engagement and incorporates program elements to build program capacity and continuity to increase student learning and advancement to rigorous STEM content.

Overview of ASPIRE

At the University of California, Irvine, a suite of k-14 outreach programs have been developed with specific emphasis on the Engineering and Technology components of STEM to prepare youth with essential 21st century skills for career success. Experiential learning has been utilized as the platform across all of the programs. For the ASPIRE program, high school students entering grades 11 and 12 are the target audience.

ASPIRE is a two-week residential summer outreach program with emphasis on the engineering and technology components of STEM to prepare high-school students with 21st century skills of critical thinking, collaboration, communication, and creativity. The program also enhances high school juniors and seniors confidence to enter the dynamic workforce of the future, which requires understanding of basic structure, materials and electrical design and computing. The entire curriculum is designed with engaging hands-on projects under the supervision of faculty and graduate mentors. Students are introduced to the fields of computer science and engineering through project-based learning, an experiential learning pedagogy that focus on excitement and engagement, and applying the scientific method and engineering process. Each project exposes students to problem solving, computer programming/coding, rapid prototyping, and manufacturing. At the end of the program, students complete a technical presentation to demonstrate mastery of these principles. Additionally, throughout the ASPIRE program, students engage with their peers, form networks, and gain a sense of community.

The primary goals of the program are to:

1. Engage students in STEM by increasing their awareness, interest, and motivation about STEM careers and preparation for college majors in STEM through speakers, workshops, and lab tours (Engagement)
2. Improve students' skills needed to advance to rigorous STEM and quantitative content through coding and the engineering design process (Capacity)
3. Continue to provide students support and programmatic opportunities in STEM through ongoing communication and connection with other STEM programs (Continuity)

To achieve the program's capacity goal, ASPIRE also has student learning objectives. After participating in the program, students are able to:

1. Use basic coding and engineering skills to operate the Raspberry Pi, use computer aided design software, and rapidly prototype their project idea
2. Design an operational project that employs a Raspberry Pi as part of an IoT network
3. Demonstrate 21st century technical skills (coding, sensing and actuation, and microcontroller implementation) through an operational project
4. Explain the fundamentals of IoT through technical presentations and project demonstrations
5. Solve problems as a team on discipline specific engineering design and computer science challenges

To accomplish these program goals and student learning objectives, ASPIRE uses experiential learning in order to teach students how to code and carry out the engineering design process. Engineering and computer science faculty and undergraduate and graduate students serve as instructors and supervise hands-on projects. STEM professionals participate in the program as mentors and speakers for career and professional development topics.

ASPIRE Curriculum and Schedule

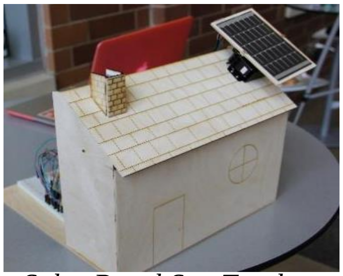
Experiential Learning: ASPIRE uses experiential learning to excite and engage students in STEM. Students learn by doing through mini-projects led by faculty and students in engineering and computer science. Some of the mini projects include creating a game using Scratch, designing a stop light circuit using Raspberry Pi, programming a sensor and actuator in Python, and creating a keychain using a computer aided design (CAD) software, 3D printer, and laser cutter. Together, all of these mini-projects provide students the foundation to create more complex projects using Python, Raspberry Pi, and rapid prototyping and fabrication technologies.

Project Theme: Each summer, a project theme or application is selected to provide a common ground for students to explore ideas and design projects. For the 2015 and 2016 programs, the project theme was Internet of Things (IOT), an emerging field of connectivity with a network of physical devices, vehicles, buildings and other things, embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to communicate wirelessly through the Internet [12]. Students worked in teams of two to build a project to solve an IOT problem by developing a project that included a network of physical objects or “things” embedded with electronics, software, sensors and connectivity that allowed data to transfer over a network without requiring human-to-human or human-to-computer interaction.

Engineering Design Process: There are 8 steps in the engineering design process: 1) define the problem; 2) do background research; 3) specify requirements; 4) brainstorm solutions; 5) choose the best solution; 6) do development work; 7) build a prototype; and 8) test and redesign. ASPIRE participants go through each step of the design process. During week 1, student teams are required to define a problem that they can solve with an IOT solution and conduct background research to create their idea. They also identify design requirements and begin to brainstorm solutions for their IOT problem. During week 2, student teams choose their best solution and design, code, and build their prototype. By the end of the program, student teams have an operational prototype that they have tested. Appendix A displays a detailed schedule of the two-week program.

Engineering and Computing Elements: While ASPIRE has a strong emphasis on hands-on application in design, coding, and manufacturing, students are also exposed to different engineering and computing disciplines through lab tours and guest speakers. These disciplines include, civil and environmental engineering, electrical and computer engineering, biomedical engineering, chemical engineering, materials science engineering, computer science, and computer game science. After exposure to these disciplines, ASPIRE participants work in teams of two or three solve a problem they choose in one of the aforementioned fields. The 2015 and 2016 ASPIRE program resulted in over 20 operational IOT projects. Below are brief descriptions of a selection of past projects, including the STEM field associated with the projects.

Environmental Engineering: The Solar Panel Sun Tracker was a device that automatically followed the sun's position. It used light sensors, which autonomously adjusted the panel's position to the optimum angle for solar energy intake, to increase overall efficiency of the panels. The tracker was designed to help make solar panels more cost efficient and competitive against non-renewable sources of electricity, such as coal, which pollute the atmosphere.



Solar Panel Sun Tracker

Electrical and Computer Engineering: The Intellock project was a locking device created with the idea of providing a seamless entry to a home without having the concern of carrying or misplacing keys. The purpose of the Intellock was to provide a keyless entry into a room by using the raspberry pi and sensors to relay information. When approaching the door at a certain distance, the ultrasonic module detected movements and sent a message to the raspberry pi. The raspberry pi then activated a camera that was capable of detecting faces and took a photo of the space over a 10-second period. The picture was then uploaded to a mobile device to await a command to unlock the door if the facial recognition was a match.

Interllock

Biomedical Engineering: The Pulse Wearable Device was created to help people find and track their heartbeat. The device was designed to be used in medical and athletic settings to provide a proper heart rate reading and track users' health status and endurance capability. It also used a pulse sensor to record one's heart rate and convert it into data that was projected onto a neopixel ring.

Pulse Wearable Device

Profile of Program Participants

ASPIRE is open to high school juniors and seniors, especially students who have interest in engineering and/or computer science, but lack experience or exposure in engineering and computer science. This program typically includes students who do not have engineering and computer science courses at their high school or a robotics or STEM-competition teams. There are also a few students in each cohort that have recently considered engineering and computer science as a college major in the last year or two and are often underprepared for a rigorous engineering or computer science program at a 4-year institution. For these students and the rest of the students in the program, we share different paths to a Bachelor's degree, such as pursuing the community college route and then transferring to a 4-year institution.

Applicants are required to have a minimum unweighted grade point average (GPA) of a 3.0. An unweighted GPA is a common way to measure academic performance in high school without considering the difficulty of the courses. ASPIRE uses this requirement to align with UCI's selection criteria for freshmen admission. California resident must receive a 3.0 GPA or higher in academic subject requirements, also called "A-G" requirements during grades 10 and 11. These requirements include: a) two years of history/social science; b) four years of English; c) three years of mathematics; d) two years of laboratory science; e) two years of a language other than English; f) one year of visual and performing arts; and g) one year of college preparatory electives. An unweighted GPA was also used to reduce the chance of overlooking applicants from disadvantaged schools that may have limited honors and advanced placement (AP) courses.

Recruitment: The program targets students from underrepresented groups in STEM, including women, students of color, students from low-resource communities, and students with limited exposure to engineering and computing. ASPIRE uses a multipronged approach to recruit students for the program, including attending college fairs and sending promotional emails and flyers to teachers and counselors. ASPIRE is promoted to students who participate in university-sponsored programs that serve students from underrepresented groups and disadvantaged schools in Southern California. Promotional material, including emails and flyers, is also sent to disadvantaged high schools outside of the university's network and faith- and community-based organizations, such as churches, Boys and Girls Clubs, and Girls Who Code. Many of the faith- and community-based organizations have a large percentage of students from backgrounds underrepresented in STEM.

Application and Selection: The ASPIRE application consists of a background form, essay, resume, letter of recommendation, and transcript. For the 2015 and 2016 programs, ASPIRE received over 250 applications. Among these applications, 41 very talented and motivated high school juniors and seniors have participated in the program from 33 high schools in Southern California. Selection was based on five criteria described below:

- Academic Preparation: Completion of at least two math and science classes.
- Motivation: Student has demonstrated involvement and interest in STEM outside of class.
- Persistence: Student has demonstrated the ability to be adaptable and overcome challenges.
- Transformation: Student has demonstrated that ASPIRE will provide exposure to new knowledge, skills, abilities, and/or mentors.
- Maturity: Reference letter demonstrates students' ability to live independently and contribute to a group setting for the duration of the 2-week residential program.

Together, the participants had an average unweighted GPA of 3.75. Out of the 41 students, 22 (54%) were aspiring engineers and 19 (46%) were aspiring computer scientists. Table 1 provides additional demographics about the 2015 and 2016 ASPIRE participants.

Table 1. Demographics of the 2015 and 2016 ASPIRE Participants

Gender	
Male	23 (56%)
Female	18 (44%)
From Underrepresented Minority Group in STEM*	34 (83%)
First Generation	14 (34%)
Eligible for Free or Reduced-Cost Lunch	17 (41%)

**The underrepresented minority group includes African-Americans, Latinos, Hispanics, and Native Americans.*

Program Survey Analysis and Results

The goals of ASPIRE are to: 1) engage students in STEM by increasing their awareness, interest, and motivation about STEM careers and preparation for college majors in STEM through speakers, workshops, and lab tours *(Engagement);* 2) improve students' skills needed to advance to rigorous STEM and quantitative content through coding and the engineering design process *(Capacity);* and 3) continue to provide students support and programmatic opportunities in STEM through ongoing communication and connection with other STEM programs *(Continuity).* Prior to ASPIRE, 75% of the participants had had no prior experience with engineering and computer science. After the 2-week program, these students reported the following results on the end-of-the-program survey.

Level of Knowledge: The majority of the participants rated their level of knowledge for different engineering and computing skills as average, above average, or well above average compared to their high-school peers. Several students rated their computer science skills below average. This outcome could be a result of having a cohort of students, where half are interested in engineering majors and the other half are interested in computer science. It is likely that a couple of students who expressed interest in engineering had more difficulty or less interest in learning some of the computing aspects of the program.

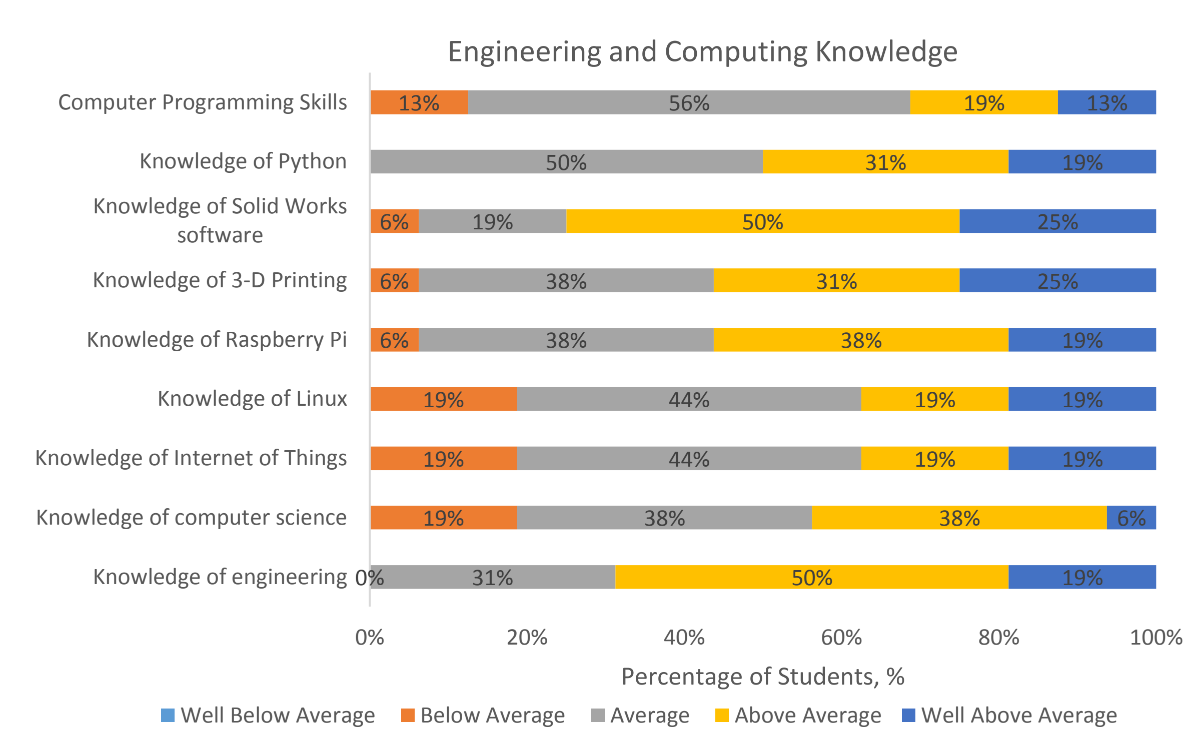


Figure 2. Engineering and computing knowledge at the end of the program compared to their high-school peers.

Critical Thinking: All of the participants rated their different levels of critical thinking as average, above average, or well above average compared to their high school peers.

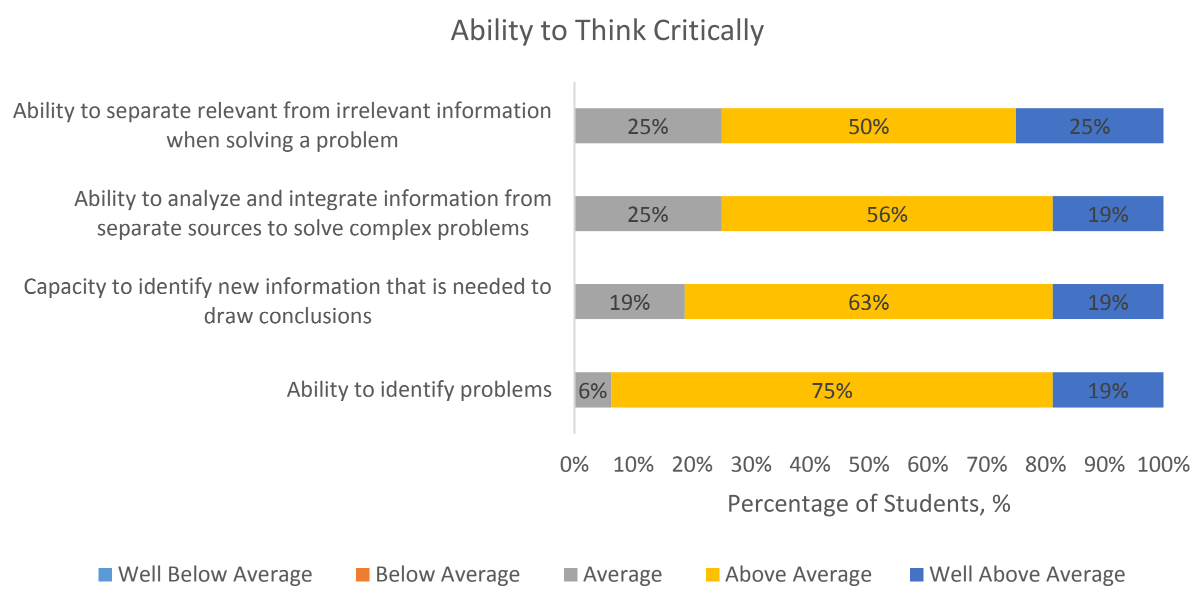


Figure 3. Critical thinking ability at the end of the program compared to their high-school peers.

Collaboration: Majority of the participants rated their different levels of collaboration as average, above average, or well above average compared to their high school peers.

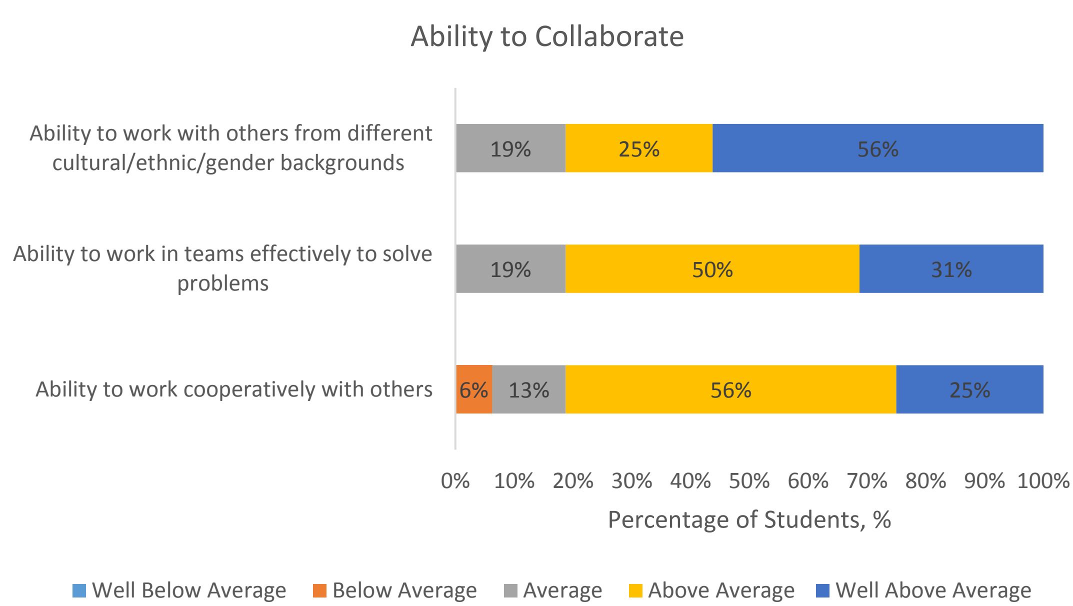


Figure 4. Ability to collaborate at the end of the program compared to their high-school peers.

Communication: There were a couple of students who rated their communication skills below or well below their peers. The rest of the students rated their different levels of communication as average, above average, or well above average compared to their high school peers.

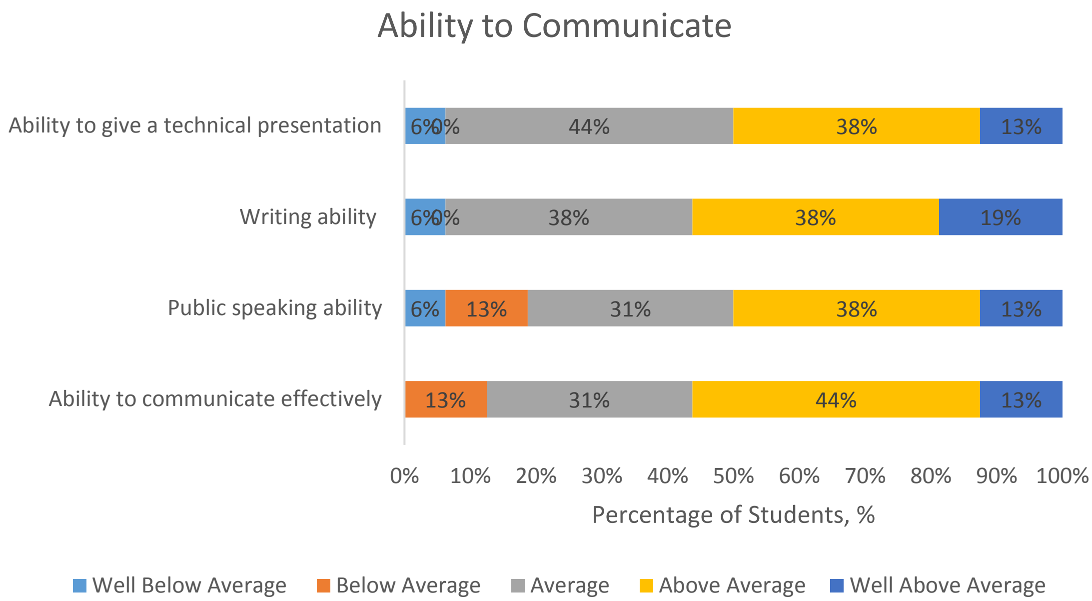


Figure 5. Ability to effectively communicate at the end of the program compared to their high-school peers.

Confidence: Majority of the participants stated that the program made them feel confident in their ability to perform tasks that will allow them to succeed as a student in the fields of Engineering and Computer Science.

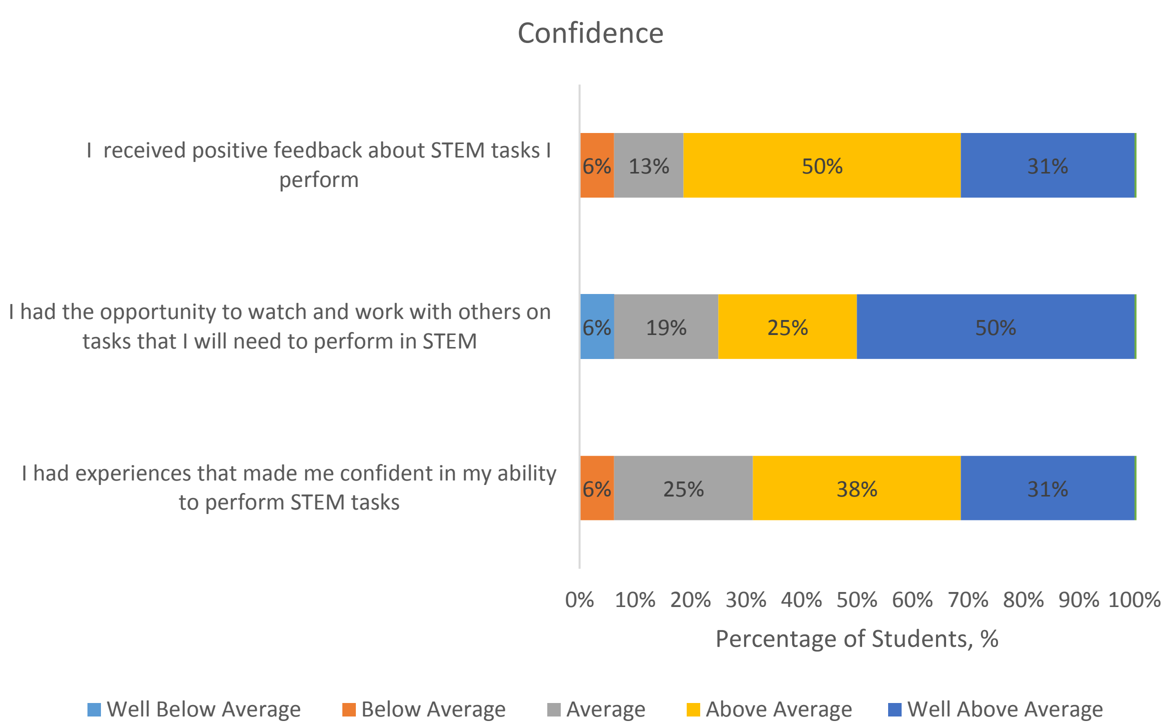


Figure 6. Confidence level at the end of the program compared to their high-school peers.

Engagement: Below are anecdotal comments from the open-ended questions about impact, interest, and understanding of different topics of ASPIRE:

- My interest in engineering and computer science was already as high as I thought possible, but the program made that interest even greater.
- EECS (Electrical Engineering and Computer Sciences) used to be my backup major, but I've become a lot more interested in it since I started ASPIRE.
- It gave me new ideas for careers, and now I debate about which major I want: Computer Science or Software Engineering.
- It has impacted my knowledge (of) various types of engineering. For example, I didn't know about civil, environmental, or biomedical engineering. In computer science, my interest went down a little because now I know how much time and effort it goes to inputting codes or make the raspberry pi function.
- It showed me all the hard work everyone (does) and the problems engineers deal with. So it gives me a drive to work harder.
- I got clarification on the major I actually wanted. I also met minorities in the industry, which encouraged me to think I can do it.
- Before I came here I was debating between civil and mechanical engineering, but after going to this camp, I realized that civil engineering isn't quite cut out for me, but materials is maybe a better choice.
- The program made me feel more confident about going into Engineering.
- I know for a fact computer science isn't for me now
- ASPIRE made me even more interested in computer science (due to all the presentations) and it has encouraged me to seek a computer science and engineering degree
- Coding seems fun, but (I) need more time and practice to fully grasp the basic ideas of it.
- It has increased my knowledge and interest, however I'm still unsure if it is the career for me.
- I thought I strictly wanted to do mechanical or biomedical engineering, but after coming to this program, I will be looking (into) to electrical and computer science engineering as well.
- It has helped me believe in myself.
- Discouraging, I have a lot to learn about coding and computer science.
- ASPIRE has changed my interest in engineering and STEM into a sure thing by having all the speakers and seeing so many of my peers.

ASPIRE participants are developing essential 21st century skills that are critical for engineers and computer scientists. They are also developing confidence in their ability and building a sense of community in STEM. We anticipate that this new knowledge, increased confidence in STEM, and network of support, will motivate students to pursue STEM-preparation courses in high school and choose a STEM major in college.

Conclusion

All of the students who participated in ASPIRE have expressed interest in engineering and computer science. In the future, the project team is exploring additional assessments to measure the students' interest in different aspects of engineering and computer science. Through the experience and knowledge gained from the ASPIRE program, it is our hope to broaden outreach through expansion of university partnerships with corporations, high schools and community colleges throughout Southern California. Leveraging the support of corporate partners and volunteers who are leaders in their fields can have a transformational impact on K-14 outreach and retention programs. Some of the challenges ASPIRE face are space and budgetary limitations. Each summer, the program accepts approximately 20 students out of over 120 motivated high school juniors and who apply annually to the program. As a result, more than 100 students miss the opportunity to take advantage of the resources, guidance and strong network provided through the program. As such, we plan to expand ASPIRE by creating a virtual component to keep students engaged in STEM (*continuity component of the ECC Trilogy)*. Because of our commitment to maintain contact with students throughout the year, the virtual community will be designed to follow up with students and offer them a forum to connect with each other. This connection will deepen their engagement in their studies while providing an avenue to address obstacles to achievement. The virtual environment will allow students across Southern California to interact with their peers, to complete online coursework and projects in engineering and computer science during the academic year. Students will also receive online mentorship from university faculty, students, and industry professionals through webinars and question and answer sessions.

Acknowledgements

We would like to thank the Broadcom Foundation, University of California, Irvine's Sameuli School of Engineering and Donald Bren School of Information and Computer Sciences for their generous support to fund this program. Additionally, we would like to acknowledge the Office of Access and Inclusion's staff and American Society for Engineering Education's paper reviewers for their suggestions.

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Appendix A: ASPIRE Schedule

Week 1	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
7-7:30am		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
7:30-8am							
8-8:30am							
8:30-9am		Program Overview	Check-In	Code Fun	Code Fun	Code Fun	Flex Time
9-9:30am		Icebreakers	Solid Works	Intro to Adv. Python	Python and GPIO Coding	Lab Work	
9:30-10am							Hike and Beach
10-10:30am							
10:30-11am							
11-11:30am		Intro to Linux and Raspberry Pi	Intro to IOT	Engineering Overview	ICS Overview	Admissions Overview	
11:30-12pm							
12-12:30pm		Lunch	Lunch	Lunch	Lunch	Lunch	
12:30-1pm							
1-1:30pm		Energizers	Energizers	Energizers	Energizers	Energizers	
1:30-2pm		Intro to Linux and Raspberry Pi cont.	Scratch, Intro to Circuit Basics, and GPIO Coding	Eng/ICS Overview	Eng/ICS Overview	Eng/ICS Overview	
2-2:30pm				Build, Design, and Test in Lab	Build, Design, and Test in Lab	Build, Design, and Test in Lab	
2:30-3pm							
3-3:30pm	Check-in	FABWorks Tour					
3:30-4pm							
4-4:30pm		Project Overview	Bill of Materials Due	Design Review		Design Review	Flex Time
4:30-5pm							
5-5:30pm		Dinner	Dinner	Dinner	Dinner	Dinner	Dinner
5:30-6pm							
6-6:30pm	Welcome Meeting/ Icebreaker /Dinner	Scavenger Hunt	Project Time	Project Time	Project Time		
6:30-7pm							
7-7:30pm						Movie Night	Flex Time
7:30-8pm							
8-8:30pm	Flex Time						
8:30-9pm							
9-9:30pm		Flex Time	Flex Time	Flex Time	Flex Time		
9:30-10pm							
10-10:30pm							
10:30-11pm							
11-11:30pm							
11:30-12am							

Week 2	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
7-7:30am	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	
7:30-8am							
8-8:30am						Practice Presentation	
8:30-9am		Code Fun	Code Fun	Code Fun	Code Fun		
9-9:30am	Flex Time	Design Review & One-on-One Coaching	Project Time	Project Time	Practice Presentations		
9:30-10am							
10-10:30am						Set up for Symposium	
10:30-11am							
11-11:30am		Communi cation Skills	Financial Aid	Career Day		Closing Symposium	
11:30-12pm	Lunch						
12-12:30pm		Lunch	Lunch	Lunch	Lunch		
12:30-1pm	Flex Time						
1-1:30pm		Energizers	Energizers	Energizers	Energizers		
1:30-2pm		Eng/ICS Overview	Eng/ICS Overview	Eng/ICS Overview	Eng/ICS Overview		
2-2:30pm		Project Time	Project Time	Project Time	Project Time	Check-out	
2:30-3pm							
3-3:30pm							
3:30-4pm							
4-4:30pm							
4:30-5pm							
5-5:30pm		Dinner	Dinner	Dinner	Dinner		
5:30-6pm							
6-6:30pm	Dinner	Project Time	Project Time	Project Time	Project Time		
6:30-7pm							
7-7:30pm	Family Meeting						
7:30-8pm							
8-8:30pm	Flex Time						
8:30-9pm							
9-9:30pm		Flex Time	Flex Time	Flex Time	Flex Time		
9:30-10pm							
10-10:30pm							
10:30-11pm							
11-11:30pm							
11:30-12am							

**Flex Time is inclusive of free time, project time, and study time.*