BUILDERS: A Project-Based Learning Experience to Foster STEM Interest in Students from Underserved High Schools

Martha Escobar* and **Mohammed Qazi**
Oakland University Tuskegee University

Abstract

Access to enriching science programs is not equitable, with students from affluent districts having more opportunities to develop their science, technology, engineering, and mathematics (STEM) skills than students from underserved districts. The *Building Unique Inventions to Launch Discovery, Engagement, and Reasoning in STEM* (BUILDERS) program was started in 2017 with support from the National Science Foundation's ITEST program to provide students from the Alabama Black Belt with STEM opportunities to which they would otherwise have no access. This project-based learning (PBL) program uses the concept of a makerspace to allow students to explore how science and technology can be used to solve the problems that affect their own communities. During an intensive, 3-week summer experience (the BUILDERS Academy), teams of students enthusiastically use the makerspace to design, build, and test prototypes of technology-based solutions to their community problems. During this immersive PBL process, they acquire and apply STEM concepts, learn about STEM careers, and acquire valuable 21st century skills. An extension of the summer Academy into the academic year was moderately successful. Overall, these results highlight the need to make extra-curricular STEM interventions available to underserved students in order to increase equitable access to practical and enriching educational experiences in STEM.

The Southern Black Belt, named after its nutrient-rich soils that have a characteristic dark color, extends from Maryland to Texas. In Alabama, the Black Belt region is comprised of 21 counties that potentiated the American Civil Rights movement, including the march from Selma to Montgomery (1965), the Tuskegee Airmen training site (1941-1946), and the Montgomery County bus boycotts (1955-1956). The Alabama Black Belt's (ABB) legacy of plantation culture *"has left the region in a state of economic depression, underemployment, and poor social services. Once sought after for its rich soils, the Black Belt has become a region defined by its dire socioeconomic situation"* (Winemiller, nd). Alabama is the sixth poorest state in the United States, with 18.5% of its population living below poverty levels. In the ABB, poverty rates are even higher, approaching 40% in some counties (Alabama Possible, 2019). Most ABB counties are also characterized by high rates of obesity, unemployment, and out-migration, as well as low educational attainment. School systems in the region *"are characterized by high a percentage of students on the free lunch program, high dropout rates, and low expenditure per student, low test scores, high rate of uncertified teachers, and low passing rate on Graduation Exam, low ACT scores, and low percentage of students attending postsecondary institutions"* (University of West Alabama, nd).

Low academic attainment in the ABB is in stark contrast with the area's growth in science and technology jobs (including aerospace, biotechnology, biomedicine, cybersecurity and advanced manufacturing; ACES, 2019), which are typically well-paying and conducive to upward economic mobility. Indeed, 93 out of 100 STEM occupations had above-average wages in 2015, and the state's projected growth rate in all occupations by 2024 is highest for mathematical and science occupations (Fayer et al., 2017). In Alabama, engineering occupations are expected to grow over 75% by 2024, with a clear shortage of qualified individuals to fill these jobs (Alabama Department of Labor, 2014-2024 projections). The shortage of STEM talent (which is predicted to be as high as 60% of available jobs by 2025; Morrison *et al.*, 2011) is a national problem that has raised concerns that the United States may lose its competitiveness in science and engineering (Wang *et al.*, 2011) unless it can produce about 1 million more STEM graduates than it is projected to produce by 2022 (President's Council of Advisors in Science and Technology [PCAST], 2012). Thus, fostering interest in STEM fields and occupations would have the double benefit to increase the available talent in STEM at a national level, and promote upward economic mobility in economically depressed areas of the country.

Most elementary school students express an interest in science, but this interest progressively decreases through middle and high school (Archer *et al.*, 2010). Interest in STEM is also only partially associated to readiness for STEM. According to the ACT's 2017 report, about half (48%) of high school graduates express an interest in STEM, but only 21% meet STEM benchmarks, a number that has changed little since 2015. Meeting these STEM benchmarks is positively associated to college readiness for STEM majors, as well as persistence and success in obtaining a STEM major (ACT, 2017a). But these numbers do not represent all facets of the student population. Underserved students (with cumulative impact of belonging to an ethnic/racial underrepresented group, having parents whose maximum educational level is high school or lower, and belonging to a low-income household) and students from rural areas have a lower likelihood of meeting ACT STEM readiness benchmarks (ACT, 2017a). Up to 60% of the population in the ABB are under-represented minorities (URMs), primarily Black/African American, attending schools in rural districts, which puts even talented students with high affinity for STEM at high risk for failing to meet STEM benchmarks. Furthermore, meeting STEM benchmarks does not necessarily mean that students will pursue STEM careers. Even though almost half of ACT takers express an interest in STEM, only 28% of students pursuing a bachelor's degree and 20% of students pursuing an associate's degree declare a STEM major, and approximately 48% of bachelor's and 69% of associate's degree seekers drop out of their STEM major (Chen & Soldner, 2013).

In the state of Alabama, 52% of ACT takers expressed an interest in STEM but only 15% scored high in measured interest in STEM (score that points to a STEM field), with only 2% of Black/African American students meeting ACT benchmarks for STEM (ACT, 2017b). In 2019, the Governor's Advisory Council for Excellence in STEM (ACES) developed a series of 22 recommendations to improve the state of STEM education in Alabama. The first of these recommendations is to, *"identify exemplary K-12 STEM initiatives and expand/scale their utilization across Alabama's schools, afterschool programs and other educational settings, with particular emphasis on reaching traditionally underserved populations"* (ACES, 2019, p. iv). Within this goal of STEM exploration and discovery, the report acknowledges that *"the availability of programs and initiatives favor communities and districts that have access to the most resources, knowledge and expertise," "reduced access to foundational STEM courses and out-of-school STEM learning experiences for students who attend high-poverty schools or who live in rural districts hinders*

*Corresponding author

the maturation of a diverse talent pool in Alabama," and *"students and parents may not always be aware of STEM-based opportunities available within their region"* (ACES, 2019, p. 10). The development of these recommendations, along with a careful study of the socioeconomic and cultural characteristics of the ABB, led to the development of a novel, project-based learning (PBL) program, to provide STEM experiences to students in rural and urban school districts in the ABB. The program, *Building Unique Inventions to Launch Discovery, Engagement, and Reasoning in STEM* (BUILDERS) was started in 2017 with support from the National Science Foundation's Innovative Technology Experiences for Students and Teachers (ITEST) program. The core intervention of the BUILDERS program is an intensive, short-term summer Academy (the BUILDERS Academy). Academy participants were also invited to participate in an academic-year maintenance and support program. Below, we describe the primary components of the BUILDERS program, some of the student outcomes observed across three years of implementation, and discuss the successes, limitations, and possibility for expansion of the program.

The BUILDERS Academy

Theoretical framework

One of the main characteristics of traditional STEM education is that the different disciplines that make STEM are taught as isolated subjects with little interconnection. For example, mathematics and science are taught as separate disciplines (Blackley & Howell, 2015; Wang *et al*., 2011), and the relationship they have with engineering and technology are rarely made explicit (Hoachlander & Yanofsky, 2011). More recently, the focus has shifted from pure STEM to an integration with non-science disciplines such as the arts and design in what has come to be known as the STEAM movement. Contemporary conceptual frameworks for STEM education have suggested that STEM should be taught as an integrated system, considering that the real world is not comprised of isolated disciplines. One way to provide interconnected STEM experiences is through informal learning opportunities, especially those in which engineering design requires basic concepts from science and mathematics that must be supported with understanding of technology. Such integrated approaches tend to increase academic performance (e.g., Hinde, 2005), motivation (e.g., Wang *et al.*, 2011), and interest in STEM (e.g., Mustafa *et al.*, 2016).

PBL provides an ideal framework to integrate multiple disciplines taught in the classroom ('classroom science') and highlight their utility in their real world ('real science'), a connection that has proven necessary to increase interest, motivation, and persistence in STEM (Zhai *et al.*, 2013). Our view of PBL is consistent with that of Schneider and colleagues (Schneider *et al.*, 2002), who suggested that PBL should be designed so that it does, *"(a) engage students in investigating a real-life question or problem that drives activities and organizes concepts and principles; (b) result in students developing a series of artefacts, or products, that address the question or problem; (c) enable students to engage in investigations; (d) involve students, teachers, and members of society in a community of inquiry as they collaborate about the problem; and (e) promote students' use of cognitive tools."* (p. 411).

Considering the unique experiences of students in the ABB, the BUILDERS program framed these informal learning opportunities around awareness of community problems. The goal was to frame the STEM activities as part of the students' real life, as making these connections leads to 'authentic' science learning which has been shown to increase interest in STEM (e.g., Cleaves, 2005; Maltese & Tai, 2010; Tindall & Hamil, 2004). Furthermore, setting the experience in a PBL framework allowed students to take a more active role in their learning experience, while their teachers acted as facilitators rather than leaders. This strategy is known to empower students to integrate theory and practice, motivate research to address the problem, and apply the knowledge obtained to develop a solution to a problem (Savery, 2006).

Students worked in developing technology-based solutions for their community problems, and were asked to present the thought process that led to the solution, the STEM concepts they used to achieve the solution, and the product that could provide the solution. These presentations to both the group participating in the Academy and a larger group of community members (including parents) were expected to be beneficial, as presenting one's work to an audience can increase self-efficacy and interest in STEM careers (Broder *et al.*, 2019). All Academy activities took place in a makerspace, which was set up in an open area with tables and space for students to build and test their products.

Program recruitment

Over the course of three years, three ABB school districts and a total of 4 high schools in those districts agreed to participate in the BUILDERS program. The smallest of these schools, located in a rural area, is a single-building school that serves approximately 300 PreK-12 students, whereas the largest of these schools, located in an urban area, serves approximately 1,500 9th-12th grade students. One-to-three teachers were recruited at each school each year. Teachers were expected to serve as mentors and guides for students throughout the summer Academy, and then guide the academic year support program. All teachers were certified science or mathematics teachers, and were compensated for their participation in the program.

Student recruitment for the summer Academy was done the preceding spring through the program website, social media (tagging the schools, districts, and individual teachers), word-of-mouth, and flyers distributed by each school to students completing the 9th, 10th, or 11th grade. Eligibility criteria for students included (1) being a US citizen, national, or permanent resident, (2) be registered for the upcoming school year at one of the participating schools, (3) have a minimum grade point average (GPA) of 3.0, and (4) not be part of the dual enrollment track with a local University. Although information such as race and gender were part of the application, they were not considered for program eligibility (i.e., all eligible students were equally likely to be selected for the program). Students were compensated for their participation in the program, using an installment system that encouraged continuous participation. Note that this is a departure from typical enrichment programs in which participants pay to participate. Academically-talented students in the ABB may find themselves in situations that do not favor the pursuit of extra-curricular enrichment activities due to their usual associated cost and the time investment. Most of the participants in the BUILDERS Academy work jobs that bring income that is needed by their families, and immediate income may be viewed as more important than delayed-reward investments such as educational enrichment activities. Thus, the inherent structure of per-pay STEM enrichment experiences leads to educational inequities in access to valuable STEM experiences.

Previous Academy participants were given the opportunity to apply for positions as peer mentors for incoming Academy participants. In Years 2 and 3, there were 2-6 peer mentors that provided encouragement, support, and guidance to current Academy participants. The role and outcomes observed in the peer mentors are described below. Two undergraduate and 2-3 graduate students served as near-peer mentors for the summer Academy.

BUILDERS Academy activities

Three-to-four weeks prior to the Academy, teachers met with the BUILDERS program directors (faculty at Tuskegee University and Oakland University) for a day-long workshop on implementing PBL strategies in an informal setting. In this workshop, they received information on PBL, participated in activities that exemplified work in a makerspace, and discussed strategies to allow students to guide their own learning experiences, while providing mentorship and support. The program directors had compiled a list of problems that could potentially be seen in the students' communities. Participating teachers discussed the problems and how they could relate to the state science standards. They selected a sub-set of 5-7 problems (depending on the year), which were then presented to students to select as their project. A list of problems and the students' proposed solutions are presented in Table 1.

The principles of PBL were emphasized during problem selection. All problems were framed in terms of a scientific solution being needed to resolve them (e.g.,

Proposed problem	Sample STEM concepts explored	Proposed student solutions
Design a small device (e.g., a bracelet) that can be connected to an app to monitor health variables such as breathing, pulse, blood oxygen levels, etc.	Chemical reactions Biological markers of disease	Use PH in saliva to detect blood sugar levels
Design a way to convert easily available energy (e.g., solar, mechanical, etc.) into stored energy that can be used to power a device.	Energy transformation and storage Electronics	Use solar panels to power a cooling fan
Design a portable shelter that can be used by homeless individuals into a 'privacy tent' that provides protection from the elements and provides some privacy.	Materials science Environmental science	Use a backpack to store thermo-reflective tent with solar panels to power a device
Develop a simple, cost effective device that can detect metal contamination in food/water using detectors that can be constructed from simple and easily available objects.	Chemical reactions Biological markers of contamination	Use modified pregnancy test strips to detect pollutants in water
Design an air purification system that uses common, low cost materials.	Physics Environmental science	Use home insulation for filtration
Develop a simple, cost effective device that can be used in the detection of different types of toxins, bacteria, viruses, or molecules.	Biological structures Chemical reactions	Modify a USB drive to detect a chemical in water
Create a water-resistant wearable pet device that will assist pet owners in locating their lost pet.	Materials science Computing	Develop a pet harness with GPS sensors to track a lost pet
Develop a cheap water purification system that can be used in the most remote part of the country.	Chemical reactions Environmental science	Use ultraviolet light and physical filtration to obtain clean water

Table 1 . Problems proposed to students and sample solutions

Week	Day	BUILDERS Academy Activities	Support Activities
1	Day 1	• 30 min ice breaker activity • Problem selection • Team selection	• Receive support from peer, near-peer, and teacher mentors • Consult with STEM faculty at Tuskegee University • Visit and use campus resources, laboratories, and shops with STEM faculty at Tuskegee University
	Day 2	• Brainstorming • Prototype proposal • Initiate supplies list	
	Day 3	• Create sketch of prototype • Continue working on supplies list	
	Day 4	• Work on model of prototype • Finalize supplies list	
	Day 5	• Finalize model of prototype • Present model of prototype to all Academy participants	
2	Days 1-5	• Build full-size prototype	
3	Days 1-4	• Build full-size prototype • Test full-size prototype	
	Day 5	• Present prototype to all Academy participants	

Table 2. BUILDERS Academy daily schedule

the water purification problem could not be solved by simply boiling water), students were expected to develop a product using research and design, the solution to the problem had to be achieved through collaboration of students with other students and mentors, and students had to be engaged in the use of technology to develop their product. Teacher and near-peer mentors were prepared to explain concepts (e.g., what is pH?), demonstrate how to apply the concept (e.g., show students how to measure pH), and observe and guide students as they tried to apply this knowledge.

The BUILDERS Academy met at the campus of Tuskegee University for the duration of the Summer Academy, which took place over three weeks in the month of June. The Academy provided transportation in school buses for students, who congregated at specified pickup points (in most cases, their school parking lot). Students arrived at 9:00 am, received a snack at 10:00 am, lunch at 11:30 am, and prepared for departure at 2:30 pm. Students from the most distant school had a commute that approximated 1 h each direction, so they committed to the Academy for a total of 7 h per day.

Daily activities for the 3-week Academy are presented in Table 2. The first day of the Academy, students were presented with the set of problems that had been pre-selected by their teachers, and they were asked to rank these problems based on their personal interest. Then, students engaged in an ice-breaking activity that introduced them to the concept of a makerspace. For example, students were asked to form groups of four, given very common materials (e.g., cardboard, foam, cloth scraps, bubble wrap) and asked to build a sound-attenuating enclosure that could mask the sound of a ringing cell phone. Peer mentors approached each team and showed them how to use a sound pressure level (SPL) meter to record the intensity of sound of their cell phone ring before and after being placed in the enclosure they created. Students were given a time limit (1 h) and upon completion of the activity, each team provided their difference scores (sound outside the enclosure [Hz] – sound inside the enclosure [Hz]). This led to a brief discussion of why some teams were more effective than others. Teacher mentors encouraged students to come up with hypotheses of why some enclosures were more or less effective than others, answered questions, and relied on graduate student mentors to explain some technical questions. This open discussion resulted in students quickly gaining information about the physics of sound waves, the properties of different materials, the anatomy of the ear, and product testing. During the discussion, students were free to test new hypotheses (e.g., change a material or the position of the phone) and quickly experience the application of the concept (see Figure 1A-D). Students were also guided on a process to reflect on their team dynamics as they came to resolve the sound attenuation problem (e.g., How did you come up with a solution? How were team member's opinions integrated into the solution? How did the team collaborate?). This reflection was aimed to assist students with preparing for the teamwork that would (later) be needed to successfully work on their prototypes.

While students engaged in the ice-breaking activity, teachers reviewed the rankings they provided for the proposed problems, and created teams of 4-5 students

Figure 1. Ice-breaker activity

Note: ***Panel A.*** **Student teams work to create a sound-attenuating enclosure that can muffle the sound of a ringing cell phone using simple recycled materials.** ***Panel B.*** **Peer-mentors assist students with using materials and developing the enclosure.** ***Panel C.*** **Students present their sound-attenuating enclosure to the group, and demonstrate the effectiveness of their enclosure using an SPL meter.** ***Panel D.*** **A graduate student mentor discusses the physics of sound transmission with student participants.**

based on their interests. Thus, each team had a problem to solve, and there were 1-3 teams working on a given problem at any given time. However, each team was free to provide their own solution to their problem, and they were encouraged to address the problem specifically for a given situation. For example, the problem, 'using alternative energy' could be addressed by creating a way to store energy to power a specific device (rather than creating a power source that could simultaneously work to charge many devices). Their task was to create the prototype of a product that could address the problem they had defined, with the restriction that the product should be (1) portable, (2) inexpensive, (3) made of readily available materials, and (4) built in the makerspace. Starting on Day 2, students brainstormed, used online and campus resources (including consultation with STEM faculty and lab/shop visits), sought guidance and assistance from teacher, peer, and near-peer mentors, and drew plans for their product prototype (see Figure 2A). Students were free to use the materials available in the makerspace, as well as request materials needed to complete the prototype. Each team was given a budget to acquire all required materials and supplies. Engineering faculty were available to discuss materials lists and budgets with students, emphasizing the fact that to build a successful prototype, the problem and solution have to be well-defined, and the materials be carefully selected to remain within budget. By the end of Week 1, students had a model prototype that helped them verify the viability of their product (see Figure 2B). The remaining days of Week 1 as well as the entirety of Week 2 and most days of Week 3 were dedicated to research, construction, and testing of the prototypes. Students were asked to record their experience in project notebooks (see Figure 2C) and develop an e-portfolio that recorded every step of their process, including successes and failures. They were cautioned that not all prototypes would be successful, but that those failures could be used as 'versions' of an ongoing project, and were encouraged to record the steps they had used to solve the problems they encountered. On the last day of Week 3, each team had a prototype (see Figure 2D), which was presented to all Academy participants, as well as interested individuals that visited the Academy (e.g., faculty, Deans, non-participating teachers, a district superintendent).

Mentoring in the makerspace. The mentoring structure for the Academy is presented in Figure 3. During the PBL-training workshop, *teacher mentors* also received training to mentor students in the makerspace. To facilitate their understanding of the intervention, they participated in a 'mock makerspace,' in which they were given 30 min to create a weather-resistant briefcase out of a cardboard box, tape, garbage bags, and discarded foam. This experience was followed by extensive discussion on what the needs of a participant in the makerspace would be, as well as the relevance of teacher mentors being collaborators rather than leaders in the students learning process. Through the duration of the summer Academy, teacher mentors met with the PIs daily to discuss challenges in the mentoring process. Teachers that had previously participated in the intervention served as peer mentors for newly-recruited teachers. *Near-peer mentors* (graduate and undergraduate students) met with the PIs prior to starting the summer Academy, and

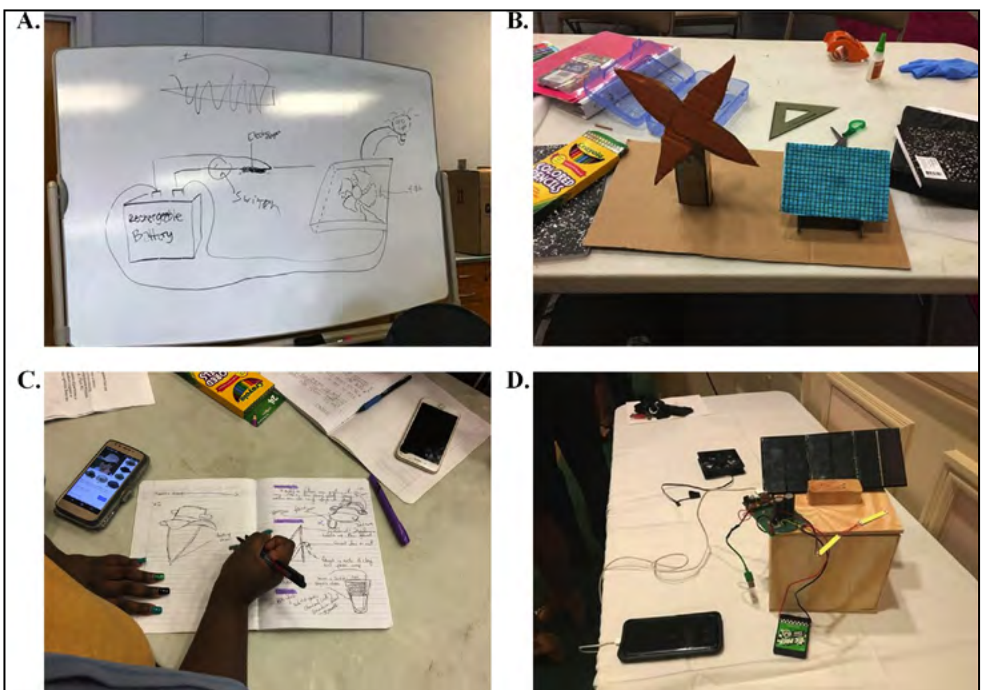

Figure 2 . Examples of student work

Note: ***Panel A.*** **Sample plans for solar energy project.** ***Panel B.*** **Model of solar energy prototype, constructed to scale.** ***Panel C.*** **Lab notebooks were used to collect students' research, experimentation, and results.** ***Panel D.*** **Prototype presented to other BUILDERS Academy participants, as well as visitors.**

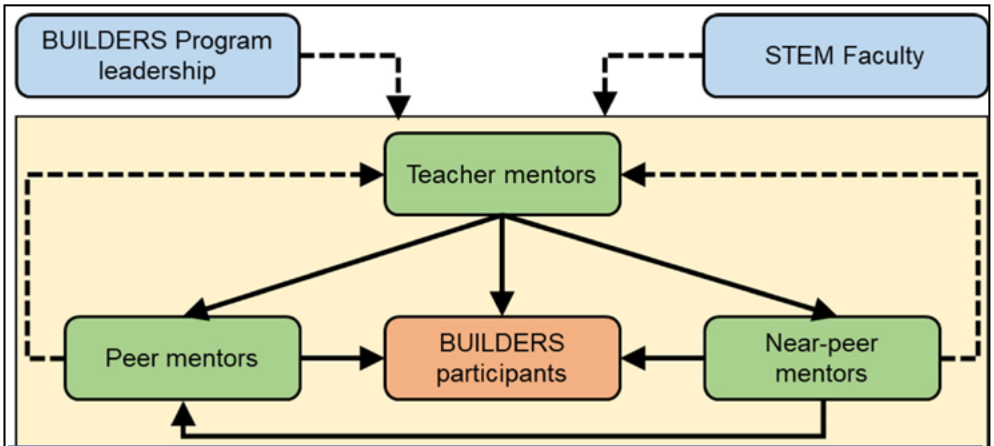

Figure 3 . Mentoring structure

Note: Teachers provided (vertical) mentoring to BUILDERS participants, peer mentors (former BUILDERS participants) and near-peer mentors (undergraduate and graduate students). Near-peer mentors provided mentoring to BUILDERS participants and peer mentors. Peer mentors provided (horizontal) mentoring to BUILDERS participants. Peer and near-peer mentors supported the role of teachers (dotted lines). BUILDERS program leadership and Tuskegee University STEM faculty provided support (dotted lines) to all individuals in the program (teacher, peer, and near-peer mentors, as well as BUILDERS participants).

were briefed on their immediate roles as peer mentors. All students had previously participated in a similar makerspace intervention, and were knowledgeable of the process of team building and prototype development. A psychology graduate student worked with the teams to assist with team cohesion and socialization. *Peer mentors* were previous BUILDERS program participants selected by the PIs through an application process in which their leadership skills, previous performance in the makerspace, and an area in which they excelled academically or had shown exceptional skills (e.g., biological concepts, or understanding of electronics) was evaluated with input from the teachers. They met with the PIs daily to determine their tasks, and joined one or more teams daily to share their experience working on their own project and suggest strategies to come up with a solution to the team's problem.

BUILDERS Academy outcomes

Throughout the three years of implementation, the Academy received a total of 228 applications, and accepted a total of 116 participants (one participant withdrew prior to starting the summer activities due to a scholastic conflict), most of whom identified as Black/African American (90%), and a majority (53%) were female. Across the three years of implementation, mentoring was provided by 10 teachers, 1 undergraduate student, and 4 graduate students. In Years 2 and 3 of implementation, there were 9 peer mentors. Note that, to provide the program with continuity, 2 teachers returned for a second year, thus providing peer mentoring to new teachers, and 3 students who were participants in Year 1 of the Academy served as peer mentors in Years 2 and 3 of the Academy (the numbers above report the number of unique teachers and peer mentors that participated in the Academy).

Demographic variable	Total	Notes
N (incomplete data)	107 (13)	Incomplete data sets were excluded from analyses
Female	60.58%	
URGs	78.50%	75.70% of students identified as Black/African American
Grade level:		
10th grade	36%	
11th grade	34%	
12th grade	30%	
Mother's highest education level (median)	High school/GED	24.30% of students did not know their mother's highest educational level
Father's highest education level (median)	High school/GED	26.17% of students did not know their father's highest educational level

Table 3 . BUILDERS participants demographic information

The data described below were collected on the first and last day of the summer Academy. Student participation in all data collection activities was voluntary, and required both parental consent and child assent. A total of 107 students agreed to participate in the data collection events for the program. Thirteen students provided incomplete data sets and were not included in the data described below. The remaining 9 students either declined to participate, did not secure parental consent, or were absent during the data collection events. The demographics of program participants are presented in Table 3.

Rationale for participating in the BULDERS program

Students were asked why they wanted to participate in the BUILDERS program. A list of potential reasons to attend the Academy was provided, and students could select as many of those reasons as they thought had motivated their application for acceptance to the program. The majority of students (60.75%) stated that they thought they could learn something useful for their future. A large proportion of the students stated that they were motivated by their interest in science and technology activities (48.60%). Almost half of the students stated that a teacher encouraged them to join the program (46.73%), whereas encouragement by family (15.89%) or friends (16.82%) was a deciding factor for a small percentage of students. Only 16.82% of students mentioned the stipend as a rationale for participation in the program.

Understanding of the makerspace concept

In the pre-participation survey, only 14.55% of students stated being familiar with the concept of makerspace. They were then given the opportunity to provide a definition of what they believed a makerspace is. Student responses were categorized by key terms, with a maximum of two key terms being assigned to each response (thus, students could provide 0 key terms if they provided no answer, or 1 or 2 key terms if they provided an answer). These key terms were not selected a priori, but were derived from students' answers. For example, an answer such as *"I expect it to be a work area,"* was coded as 'workspace/tools' and an answer such as *"I expect Makerspace to be an area where people develop things,"* would be coded as 'workspace/tools' and 'creativity/design.' Students provided a total of 151 key terms, which were grouped into 6 different categories: workspace/tools (30.46%), STEM (17.22%), creativity/design (15.23%), teamwork (13.91%), making (11.92%), and learning/future career (4.64%). These terms closely align with the description that was provided for the program in the recruitment flyer (a STEM experience for students to work in teams designing products) or reflect the term they were asked to define (makerspace).

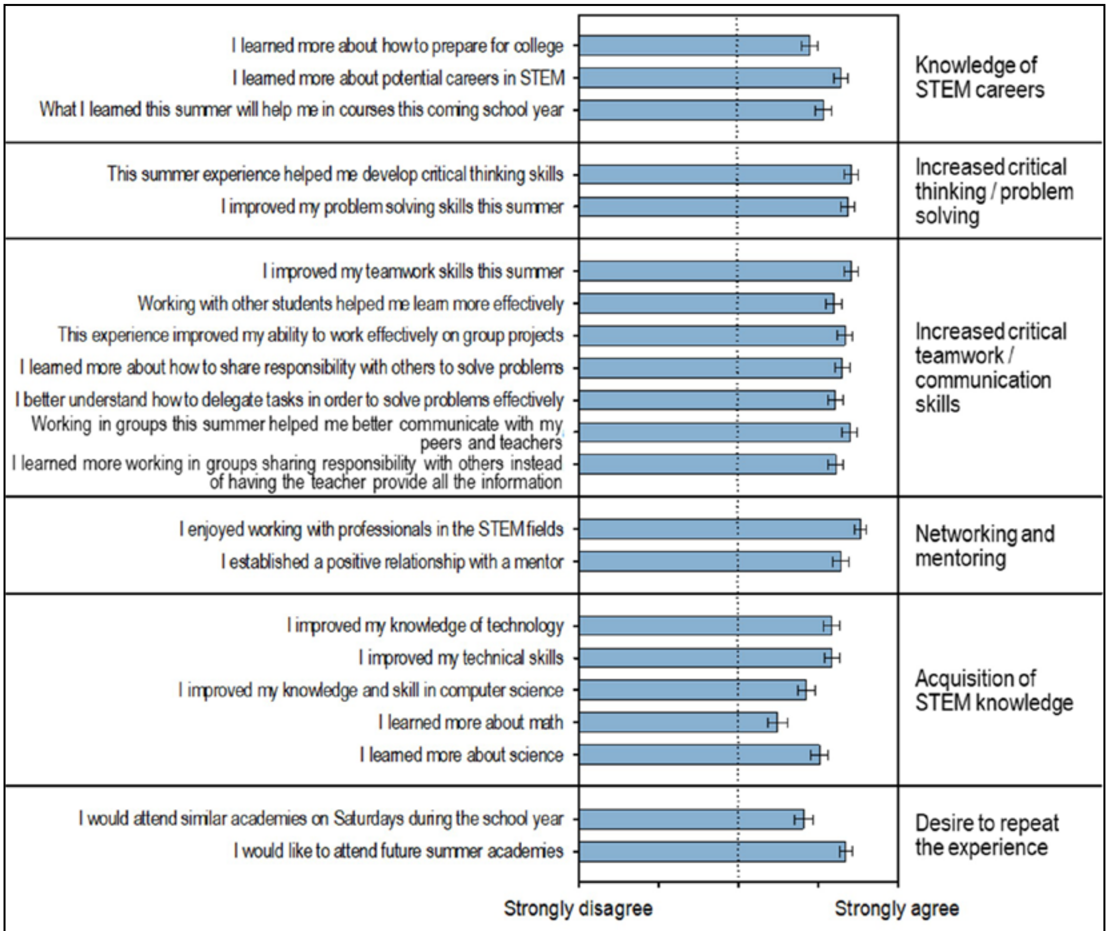

Figure 4. Students' reported Academy outcomes

Note: **BUILDERS participants were asked to rate different aspects of the Academy using a 5-point scale to reflect their agreement/disagreement with each statement. Ratings were overall positive. All ratings were significantly higher than the neutral rating (3 = neither agree nor disagree, dotted line). See text for further details.**

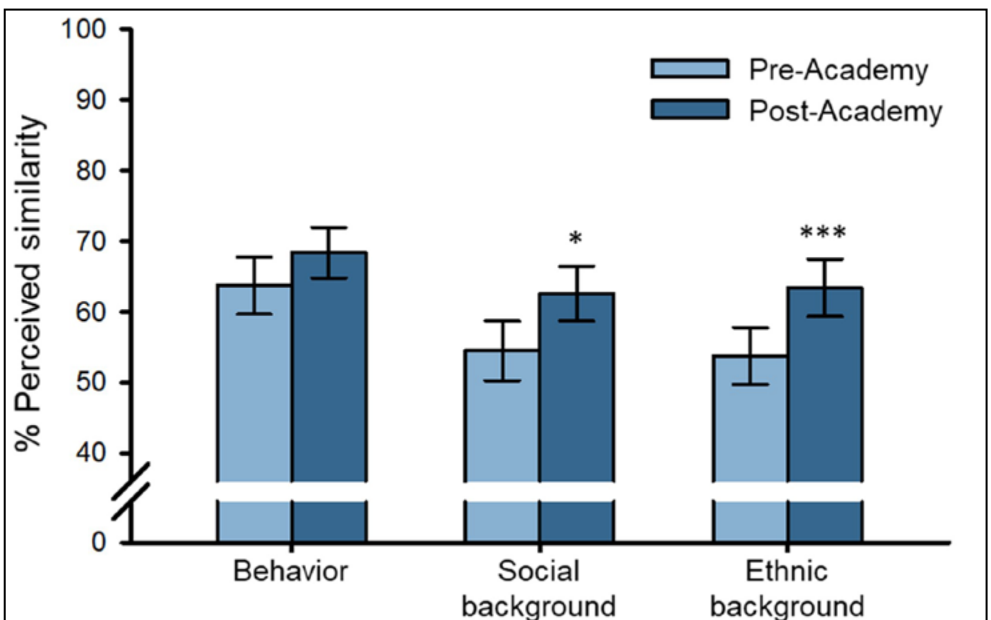

Figure 5. Professional identity

Note: **BUILDERS participants were asked to estimate the extent to which they resembled STEM professionals in the way they behave, their social background, and their ethnic background. Although students did not view their behavior to be more consistent with that of STEM professionals after than before participation in the Academy, this identification increased when they were asked to consider their social and ethnic backgrounds. See text for details. * = *p* < .05; *** = *p* < .005. Brackets represent the standard error of the mean.**

Perceived gains from participation in the BUILDERS Academy

Students' perceptions of the Academy were assessed with a series of questions targeting how much the Academy helped them gain an understanding of STEM careers, increased their 21st century skills (critical thinking/problem solving, and teamwork/communication skills), led to positive mentoring experiences, and allowed them to acquire STEM knowledge. Students' overall perceptions of the Academy were also assessed by asking them whether they would like to participate in a similar program either on weekends during the school year or again during the summer. Student responses are summarized in Figure 4. Using a scale of 1 (strongly disagree) to 5 (strongly agree), students showed an overall positive evaluation of the Academy, with all questions differing from the neutral score (3 = neither agree nor disagree), lowest $t(103) = 3.94$, all $ps < .001$. These responses were further explored with open-ended questions. Students were first asked what they gained from participating in the summer Academy. Responses were coded as explained above (see the section on *Understanding of the makerspace concept*). The majority of students stated they learned something that will be useful for a future class (68.22%), their college application (61.68%), or to find a job (52.34%). Some students thought they had learned something even if they were not certain how they would use that knowledge in the future (60.75%). Over half of the students stated being proud of what they accomplished during their participation in the Academy (51.40%), and about half thought the experience was useful to determine what they wanted to do in the future (46.73%). Students were then asked what they learned from their participation in the Academy. A majority of the student's responses related to teamwork/communication skills (35.11%), or acquisition of knowledge of STEM topics/careers (28.24%). Students also mentioned acquiring critical thinking/problem solving skills (15.27%), learning to persevere despite early failures (8.40%), specific technical skills (6.11%), leadership skills (3.05%), or how to keep an open mind for others' ideas (3.05%). Note that these are valuable 21st century skills, and students seem to have gained an appreciation of the relevance of acquiring these skills for their future professional development.

Professional identity

Students in Years 2 and 3 of program implementation (25 males and 37 females) were asked to rate the extent to which they believed their behavior, looks, social, and ethnic backgrounds resembled those of an individual in their desired field of work. The prompt was, *"Think about a successful individual in the field in which you aspire to work in the future. When you think about that individual, how much do you feel you are like that person?"* followed by specific prompts, *"your social background," "your ethnic background,"* and *"the way you behave."* Students had a response bar that they could mark at any point between *"I am nothing like that individual"* and *"I am exactly like that individual."* The response bar was divided in 100 equal intervals, and a number between 0 and 100 was given to each student's response based on where they marked the response to each of the prompts. A series of one-way analyses of variance (ANOVAs) were used to compare students' professional identity before and after participating in the summer Academy. Professional identity remained stable through participation in the Academy when participants were asked about the way they behave, $F(1, 62) = 1.28$, $p > .26$. However, professional identity increased through the Academy when students were asked to consider their social background, $F(1, 62) = 5.81$, $p < .05$, and their ethnic background, $F(1, 62) = 8.65$, $p < .005$. Thus, it seems that participating in the Academy changed students' expectations that an individual *similar to them* could be a scientist (see Figure 5).

Difficulties encountered with implementation of the BUILDERS Academy and tentative solutions

A significant difficulty with program implementation was the need to have materials available in short order for students to be able to work on their prototypes during the first week of the Academy. A list of materials was not completed by the teams until middle of Week 1, and ordering and delivery of materials took a few days, which constituted a significant delay in a short-term program and created the risk of having students sitting idle while waiting for material delivery. This issue was addressed by having teachers determine ahead of schedule the set of problems that were presented to students, and anticipating the most common materials students would need to solve those problems. Some of these materials (plywood, PVC, wires, charcoal, cardboard, batteries, fabric, zippers, etc.) are relatively inexpensive, can be easily stored, and are very likely to be used by students during the initial stages of prototype modeling and construction. Having peer- and near-peer mentors facilitate team discussion of needed materials and budget, and having consultations with teacher mentors and STEM faculty regarding the realistic needs for the project also sped up the process of ordering materials and supplies.

The physical space in which the makerspace is set up is also important to student creativity and collaboration. Using a large, open space that students could configure to suit their needs, and with easy access to an outdoor area for work that could not be completed indoors maximized the student experience. Having teams in close physical proximity allowed for fluid interactions among teams and with the mentors, which increased peer cohesion, motivation, and created a positive atmosphere that led to successful teamwork.

Academic Year Maintenance Program

One of the goals of the BUILDERS program was to support students' PBL learning of STEM through the academic year that followed their participation in the BUILDERS Academy. Consequently, teacher mentors met with students at regular intervals during the academic year to continue working on their prototypes and prepare participating students to present their fully-completed prototypes at a culminating event to be held the subsequent Spring. Although teachers tried to consistently meet with students, the maintenance intervention was overall less successful than the summer Academy. The greatest difficulties with the implementation of this portion of the program was for teacher mentors to identify a time to meet with the full team of students and for the students to make alternative transportation arrangements to convene before and after school. Having the school commit a physical space to set up the makerspace was also difficult, despite their enthusiasm to offer such a space as an opportunity to their students. Finally, conflicting academic events made it difficult for all students to attend the culminating event that was scheduled for the spring semester. For example, in Year 1 of implementation, two of the participating schools had conflicts with a revised schedule for spring exams that made it impossible for students to be absent for a full day to participate in the culminating event. In Year 3 of implementation, the COVID-19 pandemic-driven school closures led to abrupt termination of the academic year experience and cancellation of the spring event. For a program of this type to be successful, it is clear that efforts should be made to coordinate with schools the timing of student meetings, providing support for students who may find it difficult to attend meetings outside of school hours. The spring culminating event may also create difficulties for seniors that are completing academic requirements for graduation; coordination with school officials can increase their participation in the program.

Conclusion

High school is a critical period during which individuals begin to question their occupational future (Meeus *et al.*, 1999). Adolescents' emerging professional identity (Grotevant & Thorbecke, 1982) has long-term impact in future career selection decisions (Low *et al.*, 2005; Schoon, 2001). The BUILDERS Academy provided an opportunity for underserved youth to participate in an intensive, STEM-focused program that can increase motivation to explore STEM. The program used the main principles of PBL (students pursued an authentic scientific question, developed a product, engaged in design activities, used technology, and worked collaboratively with teachers). Although there are some conflicting results on the utility of PBL to be an effective pedagogical practice in students from underserved backgrounds (for a review, see Leggett & Harrington, 2019), most studies show that PBL interventions foster learning of science and technology concepts, as well as encourage positive attitudes toward STEM (for a review, see Hasni *et al.*, 2016), even among low-achieving students (Doppelt, 2003). The present study supports the positive impact of a PBL experience on students' attitudes toward STEM, and suggests that this type of interventions can be powerful tools to encourage students to view science as a useful tool for their professional development. Indeed, despite some difficulties with implementation, the program appears to have been successful in engaging students in scientific discovery, increasing their professional identity, and their confidence in their 21st century skills. The program has filled a void that exists at the partnering, under-resourced schools, in which there is a near absence of the advanced STEM curricula that is offered in more affluent districts. Thus, BUILDERS students have access to valuable STEM experiences that would otherwise not be possible. Further steps will need to be taken to increase the success of the academic year component of the program, but the present intervention can help increase the knowledge base on effective strategies to help students overcome the challenges of education in low-income backgrounds. Our experience also highlights existing challenges in the educational system, and suggests that short-term, intensive interventions (such as the summer BUILDERS Academy) can be a valuable way to provide enriching STEM experiences to students from under-resourced schools, which would increase equitable access to STEM education.

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Dr. Martha Escobar is a Professor of Psychology at Oakland University (Michigan). Her research interests include the physiological, cognitive, and emotional factors underlying organisms' responses to their environment, as well as the memories that develop from such interactions. She is also interested in how mentoring and support can increase interest, persistence, and success in STEM. She serves as Principal Investigator for multiple projects funded by the National Science Foundation aimed at broadening participation of underserved groups in STEM. She is also involved with multiple student and professional organizations that aim at increasing effective mentoring in graduate education.

Dr. Mohammed Qazi is a Professor of Mathematics at Tuskegee University (Alabama). As a mathematician, he works on classical research problems from the field of Approximation Theory. Dr. Qazi is also passionate about addressing inequities in STEM, and serves in leadership roles on several Alliances funded by the National Science Foundation. His efforts have the potential to broaden the participation of communities traditionally underrepresented in STEM at all levels, through implementation of research-based mentoring models. Dr. Qazi has disseminated his scientific and broadening participation research findings extensively in refereed journals with international circulation.