MOTIVATE: Bringing Out the Fun with 3D Printing and E-Textiles for Middle- and High-School Girls

Dr. Quincy Brown, Bowie State University

Dr. Quincy Brown is an Assistant Professor in the Computer Department at Bowie State University. She is a 2009 recipient of the National Science Foundation/Computing Community Consortium CI Fellows Postdoctoral Research Fellowship award. She completed her doctoral work at Drexel University where she was a National Science Foundation GK-12 and Bridges To the Doctorate Fellow. As a GK-12 Fellow she taught and developed STEM curricula for middle school students. Through her research she seeks to identify methods of facilitating human interaction with advanced technologies, including mobile devices, to support learning. Specifically, her ongoing projects examine the design of intelligent tutoring systems, delivered on mobile devices, to support middle school mathematics learning and exploring the design and usability aspects of mobile device use by children.

Dr. JAMIKA D BURGE, Information Systems Worldwide

Jamika Burge is a Senior Scientist at Information Systems Worldwide (i_SW), a technology, engineering, and research company providing high-end advanced technical, integration, engineering and analysis solutions to the US Government and other customers. From 2007-2009, she was a postdoctoral research scholar at The Pennsylvania State University focusing on community informatics. She earned her PhD in computer science and applications from Virginia Polytechnic Institute & State University (Virginia Tech), where she was a IBM Research Fellow and won an IBM Research Dissertation Fellowship. As a graduate student, her research and perspectives were featured in the New York Times and Computerworld.

She is affiliated with the Coalition to Diversify Computing (CDC), based in Washington, DC. The CDC targets students and faculty with the focus of increasing the number of minorities successfully transitioning into computing-based careers in academia, federal laboratories, and industry. As a CDC committee member, she is co-director of the Collaborative Research Experiences for Undergraduates (CREU) program and co-chair of the Women of Color in Computing initiative.

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ABSTRACT

Women, and more specifically, minority women, continue to be largely underrepresented in computing. In 2008, of the roughly 20% of women who were awarded bachelor's degrees in computer science (CS), only 5% were minority women[47]. This lack of ethnic diversity within gender diversity compounds the exigent need to promote and support minority women into the S&E pipeline. In the paper, we describe the MOTIVATE framework, developed to expose African American girls to CS, through a summer program for middle- and high-school girls. We describe our experiences implementing the framework that also included *Do It Yourself (DIY)* activities in 3D printing and e-textiles, and our results from its pilot evaluation showing that we were able to change the girls' perceptions about computing.

1. INTRODUCTION

With respect to African Americans (AAs) as underrepresented minorities in CS, the most recent data available reveals that in the US, 3.6% of undergraduate, 1.6% of master's, and 1.2% of doctoral degrees were conferred to AAs[49]. Though it is expected that fewer individuals will actually pursue a terminal degree in CS, it is clear that at every point in the pipeline, the number of AAs is disproportionately low when compared to their overall percentage in the US)[31,49]. One particularly popular effort to enhance the rigor of the high school math and science curricula and expand access to rigorous curriculum is increasing AP course-taking in the STEM content areas. In 2012 (in the US), of the 1,014 AA students taking the AP CS exam, only 252 were women, compared to 13,320 Caucasian students and 1,976 Caucasian women students[2]. Furthermore, in the previous five years, AA women have had the lowest pass rates (score = 3, 4, or 5) of all women students taking the CS AP exam[2].

We have chosen to focus our efforts on AA girls as they are the least represented demographic in computing, *even though* a survey conducted by Girl Scouts revealed that AA girls have the highest level of interest in CS careers as compared to their Caucasian and Hispanic peers[34]. Our goal is to develop a framework to engage this demographic and make computing accessible, thereby removing the mystique and "this is hard" image of CS.

The MOTIVATE framework integrates five areas that are known to impact student success in various ways: (1) technical skill development, (2) parental support, (3) non-technical skill development, (4) mentoring, and (5) informal education. The framework was implemented in the 2013 offering of a summer program for middle- and high-school girls at Bowie State University. The program enrolled 17 girls from grades 6-11 and engaged them in activities such as e-textiles, 3D printing, mobile app development, and cyber-security education.

2. RELATED RESEARCH

MOTIVATE is a framework that integrates five areas that are known to impact student success. Here, we describe each area in detail.

2.1 Existing K-12 Interventions

Previous interventions have examined the effects of technical and non-technical skills development through informal education programs (i.e., summer and weekend camp programs), mentors, and parental support in various combinations in K-12 and higher education. In fact, agencies such as the National Science Foundation have funded programs that provide interventions for underrepresented students in learning CS. While these programs are highly educational, the goal of educating substantial numbers of AA high school students has been largely unmet. CompuGirls[10] and BlackGirlsCode[6] have developed successful programs that target middle- and high-school girls, and Glitch[12, 18] was a program that focused on using game testing as a means of attracting AA high school males. NCWIT has also developed a set of best practices[28] that details the most salient components that contribute to a successful outreach program for girls. The MOTIVATE program essentially incorporates the most successful initiatives of each of these interventions and provides a comprehensive framework for teaching computing to AA girls.

2.2 Technical Skill Development

Limited access and experience have long been cited as factors contributing to girls having less confidence with computers and thus not choosing to enter computing fields[4, 14, 22]. In mixed-gender environments, boys tend to dominate computer use leaving the girls to act as bystanders. As a result, boys get more computer experience[22]. For girls, this lack of experience manifests itself through reports of low self-confidence and a dislike of computing[22]. However, research has also shown that when provided with equal access, girls perform as well as boys[22]. While there are disparities in technology access across race, gender, and even class lines, we now know that AA high-school students are interested in learning CS[19, 20]. In today's age of Internet 'connectedness' through social media, and smartphone apps, students want to learn more about how to develop their ideas for these interactions. The problem, however, is that CS courses are often *not* available to students, and even if they are, girls and underrepresented students simply do not take the classes[19, 33]. The MOTIVATE program seeks to expose girls to technical content through interactive classes that incorporate CS principles, teaching problem-solving through computational and critical thinking.

2.3 Parental Support

School-age students spend approximately 70% of their time outside of their classrooms[8]. This presents a precious opportunity to facilitate continuing education activities for students. Parents, then, play an integral role in supporting their children's education inside *and* outside of the school. Parental involvement has been shown to improve (and sustain) academic performance[25, 27, 29], and when parents engage within the larger external school community (such as after-school programs), the students, parents, and community all benefit[15, 37, 42]. A recent survey of girls in the US has revealed that one or both parents of AA girls are less likely to work in a STEM career (18%), compared to their Hispanic (23%) and Caucasian (29%) peers. Furthermore, AA girls (38%) report that their parents are less likely to approve of a STEM career when compared to their Caucasian (54%) peers[34]. Thus, the MOTIVATE program integrates support to parents, which will help to ensure that students maintain strong levels of commitment and engagement. Parents are provided with a newsletter containing information including internship opportunities for high school students and scholarship programs. We are also available to answer questions about college preparedness. (Eventually, the MOTIVATE program will offer classes for the parents in which they also learn topics such as web programming and application development.)

2.4 Non-Technical Skill Development

There is evidence that attitude, self-esteem, and morale all impact student academic achievement as much as cognitive development[24, 25, 29]. These non-technical skills, also called *character*, help computer scientists solve problems. Learning CS often requires soft skills like cooperation, communication skills, discipline, and resilience, which prepare students for tackling obstacles head-on.

To encourage non-technical skill development, MOTIVATE girls prepare presentations on a topic they most enjoyed during the program (i.e., HTML, 3D printing, robotics, etc.,), and participated in a showcase at the end of the workshop. This provides them with an opportunity to self-reflect and share how they might have overcame challenges during the course of their learning. The MOTIVATE program provided an environment in which AA girls could thrive. We want to be sure that when she walks into her CS class or joins a school Robotics Team —and is one of a few AA girls in the room – that she is not only technically capable but also has the character, resilience, and confidence to know that she can succeed.

2.5 Mentoring

The effects of mentoring have long been cited as beneficial for both the mentor and the mentee: higher salary and better career satisfaction for the mentee[13, 16] and for the mentor, an enhanced reputation for developing new talent[23, 48]. There is also evidence that the degree of similarity in race and gender mentoring (whether perceived or actual) can affect the quality of the mentoring, such that the more similar one perceives the other to be, the more the other person is liked[7, 44]. In the context of CS, peer mentoring and affinity groups have been encouraged as a means to support underrepresented students[32, 40]. This peer-based model also extends to pair-programming, which helps student pairs (and sometimes groups of three) solve computing problems more efficiently and with increased confidence[9, 46]. The MOTIVATE framework employs a multi-tiered mentoring approach through hiring undergraduate and graduate AA female student staff.

2.6 Informal Education

Many after-school and out-of-school programs have been shown to predict academic and social competence, particularly among middle-school students[17, 39]. In fact, the structured skill-building aspect of these informal education activities helps adolescent students learn to focus in "the zone", achieving *flow*, which helps them to excel academically[11, 45]. More specifically, students who report higher "flow-like engagement" in their high school math and science classes were more likely to report higher grades in college[38]. Thus, out-of-school programs such as those based on MOTIVATE, afford rich opportunities for educational advancement for students.

3. MOTIVATE IMPLEMENTATION

An additional, unique feature of the MOTIVATE curriculum is the integration of the "CS in…" track. This track is an extension of contextualized computer education[21], which teaches CS in relevant, real-world contexts and authentic learning experiences[35]. Through the "CS in…" track we provide a series of learning modules designed to spark interest in CS[5] by focusing learning across a range of applications, including robotics, health, music, and entertainment. Specifically, we focus on the relationship between CS and Art/Entertainment, Music, Security, and Robotics through a series of activities involving mobile applications development, game design, e-textiles, 3D printing, and movie-making. The MOTIVATE framework uses these activities to build knowledge of computer science and its applications.

The MOTIVATE framework was designed to be executed in summer workshop program, when the students engage in activities focused on two of the following CS Big Ideas: Creativity, Impact, Internet, Programming, and Algorithms. The summer program runs for five days (Monday-Friday) for seven hours each day. Each session concludes with a computing showcase during which girls present their work to their friends, family, and community. The camp is staffed with African American undergraduate female students who serve as near-peer role models.

We implemented the pilot for the MOTIVATE framework in the summer program, which targets middle- and high-school girls by teaching them a range of computing topics. For two years, the camp has had good success in training over fifty AA girls in computer science. The program uses some (but not all) of the components of the MOTIVATE framework, including AA mentors (near-peer and professional), and technical skill development. For the MOTIVATE pilot program, we added the non-technical skill development and parental support modules, and the "CS in…" track. We held the camp for two weeks in June 2013. There were fifteen (15) middle- and high-school girls, fourteen (14) of whom were AA, and fourteen (14) girls completed the full program. The girls were recruited from local schools and from previous camp participant lists. Of the seventeen girls, nine completed both the pre- and post- camp assessments. Three of these girls had participated in past camps.

Figure 1. Participants presenting 3D designs to group

MOTIVATE FRAMEWORK	Implementation
Technical Skill Development	HTML, CAD Modeling, Circuit Design
Parental Support	Fall Newsletter
Non-technical Skill Development	Computing Showcase, Campus Tour
Mentoring	University student peer mentors
Informal Education	Setting – Summer-time out of school environment

Table 4. MOTIVATE Framework Implementation

3.1 Creativity Focused Activities

The recent popularity of the Maker or Do-It-Yourself (DIY) movement as a method of attracting students to STEM uses focused, hands-on, construction and crafting activities. While these types of activities are easily connected to STEM, it is possible to complete DIY activities without the use of a computer or computing tools. We included creative DIY activities that combine the technical and non-technical skills that are part of the MOTIVATE framework. Here we describe two activities that involve hands-on DIY projects that make explicit the creativity and fun in computing.

3.1.1 E-Textiles Electronics

At the intersection of textiles and electronics lay a growing area known as e-textiles. E-textile projects typically include textiles (fabrics) and electronics that can be easily sewn into fabrics[26, 30]. In the camp, we used sewable electronics from the Arduino LilyPad product suite[3]. Specifically, we used the following:

- LilyPad Boards: TinyLily, LilyTwinkle, LilyPad Simple
- LilyPad Components: LED, Buzzer, Vibe, Button, Slide Switch
- Power: Coin Cell Battery Holder

Initially, we purchased the components listed above, along with conductive thread and needles with the intention of creating our own kits. It turned out, however, to be more efficient to purchase the existing kits since they are already connected to a circuit board. This also made it easier for the students to understand how the component parts worked together because they could see them on the boards.

Each participant completed two e-textile activities. The first project was designed to familiarize the girls with basic circuitry and e-textiles. Each participant created a personal design project using a tote bag, t-shirt, or felt plush character (e.g., a teddy bear), using a pre-existing template. In addition to the electronic components, puffy paints, artificial flowers, beads, and colored markers were available for decoration. The second project was group-based, allowing the girls to develop their own design ideas using one of the programmable LilyPad boards. Program staff assisted students with learning to program the boards to change the behaviors of components that are controlled by the microcontroller boards, such as LEDs that faded or twinkled fast or slow depending on the program or buzzers that were activated when a button is pressed. Projects included a plush stuffed animal, a cell phone holder that lights up, and tote bag, figure 2.

Figure 2. Banner with LEDs in clouds that includes twinkling lights

3.1.2 3D Printing

We also purchased a desktop 3D printer that uses PLA filament and prints in one color at a time[36]. Though the printer contained pre-programmed files, we wanted the girls to create their own designs. This required the use of computer-aided design (CAD) software. We surveyed free CAD software tools including Blender[41], 3dtin[1], and TinkerCAD[43]. Though other programs would allow for more complex designs, we selected TinkerCAD because of its user-friendly interface and its selection of pre-designed letters and shapes.

Each participant was able to create both personal and shared group projects. Girls were given an introduction to the CAD software prior to creating, and eventually printing, their designs.

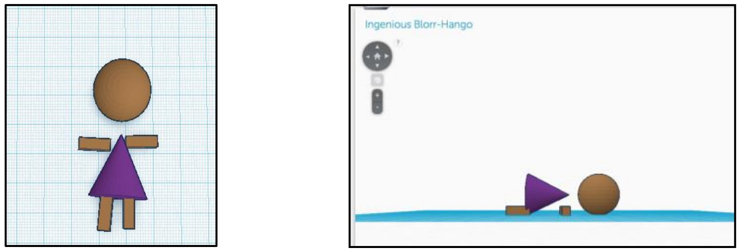

Figure 3. CAD drawn object appears aligned from top but is not when viewed sideways

4. EVALUATION OF ACTIVITIES

Summer 2013 was the first implementation of the MOTIVATE framework. As such, we do not have data regarding participants' post-camp education. Here we present our analysis of the creativity-focused computing activities conducted during the program in summer 2013.

4.1 Demographics

There were 15 middle- and high-school girls who completed the program. Girls completed a pre-program survey on the first morning of the workshop and a post-program survey on the last morning of the program. There were thirteen girls who participated in the pre-program survey and fourteen who completed the post-program survey. The difference in completion rates was due to personal scheduling conflicts that caused some girls to miss either the first or last day of the program.

Of all participants, six girls were in middle school (grades 6-8) and nine were in high school (grades 9-11). All but one of the girls was African American. Mothers' occupations ranged from teachers (3), pediatrician, lawyer, registered nurse, and an environmentalist. All but one mother finished college. Fathers' occupations also varied and ranged from pastor (2), police officer, insurance agent, and computer programmer (1). Eight, of the twelve fathers completed college.

4.2 Pre-Program Survey

We asked all students to complete a pre-program survey. We presented a range of questions, including "What is computer science?", "What does a computer scientist look like?", and "What kind of work do you think a computer scientist does?". We also asked the students if they knew a computer scientist, and we asked them questions about their parents' occupations.

When we asked the girls to define computer science, their responses included "The study of computers parts, benefits, and history", "It is the study of computers, coming up with new ways to program them and use them and figure out how they work", and "Any study or practice that has anything to do with computers".

When asked about the skills that are important to computer science, responses included, "Knowing how to use basic software such as Microsoft Word, how to create a webpage, how to get rid of viruses, "Being able to read code, program, and mathematics.", and "Hand coordination, patience, love for computer science."

When asked about what a computer scientist looks like all responses included a variation of "A normal person". One student wrote that a computer scientist is "what we usually would see on television [who] would be a smart person with glasses, wearing a lab coat stuck in a small room all day".

Six (6) girls had previously completed a STEM course in school, four (4) in an informal setting (for example, in a summer camp), and three (3) provided no response.

4.3 Post-Program Survey

For the post-survey, we asked students to provide answers to the same questions as in the pre-survey. In particular, we again asked students to answer questions about what a computer scientist does and the skills important to a computer scientist. When asked to define computer science responses now included "It is work on a computer and study stuff to make the world a better place and life much easier", "I define computer science as learning more and getting in depth info on how computers work", "The use of computers to do many creative things", and, even "fun, at the same time boring".

When asked what skills are important to computer science responses now included "To have an open mind and be creative", "Some skill are reading, mathematics, science, and technology use and understanding", "Math, science, long attention span, concentration, never giving up, and enjoying it.", and "Knowing how to program and patience."

4.4 Is Computer Science Fun?

Our pilot data represent a small sample, but our analyses indicate that the girls enjoyed the computing activities. When asked, "Do you think CS is fun?" two out of nine students indicated 'No' on the pre survey and one of the nine indicated 'No' on the post survey. One respondent who indicated 'No' on the pre-survey wrote, "Not really, because I don't have much interest and it frustrates me. I do think it is cool, but I'd rather not do it." However on the post-survey, in response to the same question, she wrote, "Kind of. The things you do are [sic] fun but the process is challenging for me". Other post-survey responses included, "I think it is fun when you finally [sic] get it right and it looks really cool. Also [sic], it is fun to learn new things and make new things."

Many students already had a positive perception of CS, so we found that their post-survey responses focused more on what can be done or made as part of CS rather than what can be learned by using computers. This shift may demonstrate that the inclusion of DIY computing activities within computing curricula can shift the focus of computing from programming and tool use to a more learning-focused activity in which computing provides a creative and engaging experience. This points to an interesting dynamic about how AA girls might associate the application of computers to their daily lives. We will further explore this finding in our computing camps.

4.5 Did We Change Their Attitudes?

At the beginning and end of the program, we asked the girls to agree or disagree with the following statements, "Studying computers in college is hard" and "I will study CS in college". Students entered values where 1 = strongly agree and 7 = strongly disagree.

Though a *t*-test produced results that were not signifcant ($p > .05$), analysis of individual data points revealed that three girls did not change their perception of the difficulty of studying CS, four girls thought CS was easier, and two girls indicated that studying CS was harder on the post-survey than on the pre-survey.

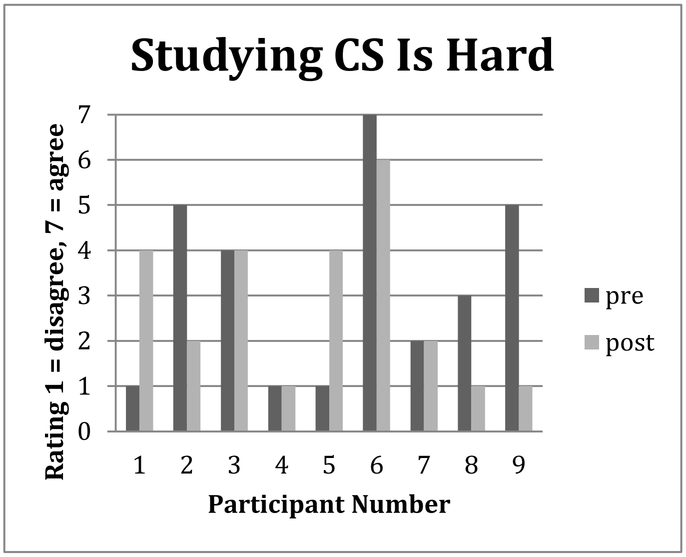

Figure 4. Difficulty of studying CS ratings

This research is the first in what we hope will be a larger collection of studies that examines AA girls and computer science education. While the sample size for this study was small, we were gratified to see an attitude shift among the participants. The girls learned, through the camp activities, that computer science can be fun and it can incorporate creativity in problem-solving. Future studies will enable us to track camp participants for longer periods of time as we explore how many students go on to college and whether they pursue majors in Computer Science or Computer Engineering.

5. LESSONS LEARNED

We learned valuable lessons in working with the students on these computing activities. Here, we offer practical suggestions to others interested in conducting similar activities.

5.1 3D Printing

Though we were familiar with using the technology with university-level students for research activities, this was our first experience using 3D printing technology with middle- and high-school students. We introduced students to 3D printing by having them watch the printing of a small object. This piqued their excitement, which paved the way for a brief introduction to the CAD software. Below, we share our lessons learned as a result of our 3D printing activities.

- ***Provide rulers so students can see the size of their designs***. The girls were not familiar with different units of measure, e.g. inches vs. centimeters. Initially, they did not pay attention to the units of measure, which resulted in designs that appeared to be properly sized in the CAD software interface, but were actually too small or too large for printing. For example, some students wanted to make rings but did not know the size of their fingers. They ingeniously created circles in CAD to represent their finger sizes, but these ‘finger circles’ were not big enough to accommodate their ring designs. This also led to several designs that were fragile and broke.
- ***Consider the time to print.*** Designs can be rapidly created using software, but given the limitations of the 3D printing technology, it took a long time for the designs to print. For example, a 2-inch x 1-inch ring took a few minutes to design, but it took 35 minutes to print

the design. The students were able to design objects at a rate that was much faster than they could be printed. This resulted in lots of unscheduled wait time.

- ***Include spatial awareness activities.*** Though the software was not difficult for the students to use some did not have the spatial awareness skills needed to create their object designs. The girls knew what they wanted to make, but they had difficulty constructing the objects using the software tools and working in 3-dimension space, figure 3.

5.2 E-Textiles

During our planning, we recognized that the girls would need to receive instruction on basic circuitry. Our focus was on developing a short, easy to understand lesson that would help the girls sketch a basic circuit. We relied on program staff (who were near-peer AA university students) to assist them with extending their basic ideas to create more complex circuits when needed. Though we planned for their lack of circuit knowledge, we did not anticipate the following issues.

- **Many students cannot sew.** We anticipated providing support to assist students with circuit design; however we did not consider that students would not be able to sew by hand. For example, the girls had difficulty using the needle and conductive thread to begin and end circuit segments, and they were unable to properly sew knots. This resulted in circuits that were not constructed well and required additional debug time.
- **Avoid intricate designs.** We pushed the girls to come up with their own design ideas. Our goal was to provide them with support, as needed, to implement their creations. However, we soon discovered that due to their unfamiliarity with sewing by hand, the girls were less cautious about crossing threads over one another. This led to projects with many instances of shorted circuits resulting from crossed threads. The simpler designs tended to use series (instead of parallel) circuits and linear (instead of curvy) paths were easier to debug and had fewer short circuits.

6. CONCLUSION AND DISCUSSION

Our goal was not to necessarily convince students to major in computer science. Data already show that there is a disconnect between interest in computer science (which seems abundant) and making the decision to major in computer science (which is much less abundant). Our goal was to make computing accessible and to remove the mystique and "this is hard" image of CS. By making the fun and creative aspects of computing more explicit, we were able to use the MOTIVATE framework to introduce students to computer science through the use of computing and online tools to create tangible objects rather than to create artifacts that exist only online.

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