Equitable STEM+CS Learning Experiences for Girls of Color: Nurturing Independent Learners via a Learning Ecosystem

Ryoko Yamaguchi, Veronica Madrigal, Jamika D. Burge, and Cyntrica Eaton

September 2022

This report is based upon work supported by the National Science Foundation under Grant No. 1752436, titled "BRIGHT-CS: Building Student Retention through Individuated Guided cohort Training in Computer Science". Any opinions, findings, and conclusions or recommendations expressed in this report are those of the author and do not necessarily reflect the view of the National Science Foundation.

Yamaguchi, R., Madrigal, V., Burge, J., & Eaton, C. (2022). *Equitable STEM+CS Learning Experiences for Girls of Color: Nurturing Independent Learners via a Learning Ecosystem*. Greensboro, NC: University of North Carolina Greensboro. https://bright-cs.uncg.edu/

This report is available on the BRIGHT-CS website at https://bright-cs.uncg.edu/

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Abstract

Purpose: There is a critical need to understand how to attract Black girls and other girls of color to the STEM+CS field. This study looked at the design and implementation of a CS learning ecosystem that supports girls of color in acquiring critical CS skills starting in middle school.

Design, methodology, and approach: This mixed-method case study included 53 girls of color in four United States middle schools. Study methods included the analysis of student surveys, longitudinal interviews and focus groups, weekly observations, and computing artifacts.

Findings: Program participants were interested in CS, were confident in their ability to learn CS, had prior coding and CS experience, and had parents and teachers who encouraged them to learn CS. But some students showed dependent learning behaviors while engaging in CS activities. These included relying on instructors and being reticent to make mistakes–behaviors that limit learning. The CS learning ecosystem supported students as they shifted from being dependent learners to becoming independent learners. Instructors sustained a growth mindset and supported productive struggle as students learned CS skills.

Originality: A CS learning system supported equitable learning experiences and helped students develop independent learning behaviors that led to deeper engagement in CS.

Keywords: Black girls, computer science, computational thinking, dependent learning, equity, independent learning, learning behaviors, learning ecosystem, middle school girls, STEM, STEM+CS

Introduction

In the United States, Black students[1] and their parents report higher interest and support for computer science (CS) than White and Hispanic students and their families (Google Inc. and Gallup Inc., 2015, 2016). Black students also report seeing more CS role models in the media than White and Hispanic students (Google Inc. and Gallup Inc., 2016). But Black students–Black girls in particular–have the lowest participation rates in CS throughout the education and employment pipeline (National Science Board, 2019). There is a clear disconnect between student and parent interest in CS and the makeup of CS pipelines.

To address this disconnect, our study looked at the design and implementation of a CS learning ecosystem that supports middle school girls of color and Black girls in particular in acquiring computer science and computational thinking (CS/CT) skills. The ecosystem[2] is a comprehensive yearlong CS learning experience that includes culturally responsive CS curriculum materials; instructors and mentors trained in culturally responsive and equitable practices; weekly CS experiences at school; and two-weeks of summer camp at a local university.

We used the following research question to guide the study:

- What are the effects of a CS learning ecosystem (i.e., BRIGHT-CS) on student engagement, learning, and persistence in CS?

[1] Our reference to Black students follows the 2020 US Census definition of Black or African American.

[2] The ecosystem is part of the Building Student Retention through Individuated Guided coHort Training in Computer Science (BRIGHT-CS) program.

Literature Review

Supporting girls of color as they engage in and learn computer science and computational thinking skills

Learning is not linear, easy, or fast, but the culture and structures of schooling can make students feel as though they are underperforming if they do not grasp concepts quickly or earn high marks on tests (Darling-Hammond, 2001; Delpit, 2006, 2012; Hammond, 2015; McGee & Stovall, 2021; Oakes, 2005). This is exacerbated when girls of color are underrepresented in gifted and advanced classes (Grissom and Redding, 2016; Oakes, 2005; Shores *et al*., 2020; Young *et al*., 2017) and in STEM+CS-focused activities (Hill *et al*., 2010; McGee, 2013; Young *et al*., 2017).

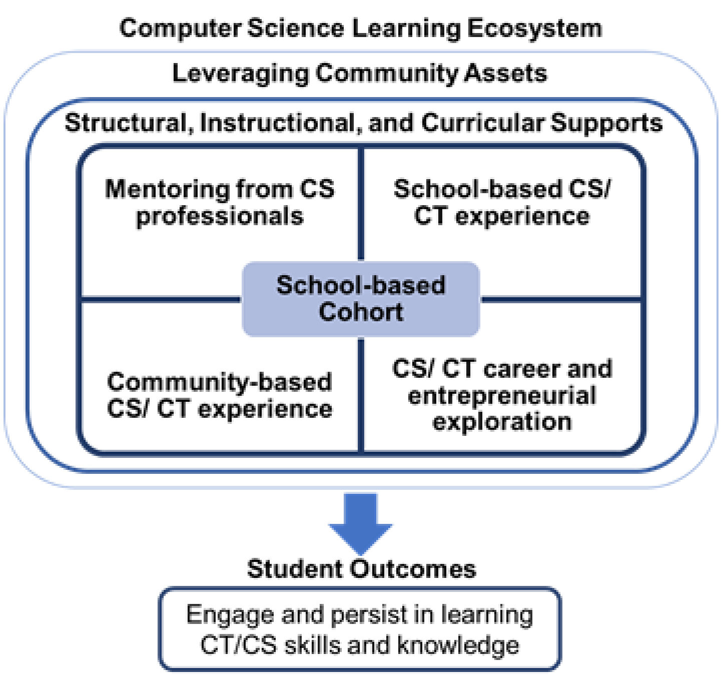
Providing equitable learning experiences is about helping students navigate learning challenges and resolving productive struggle (Nottingham, 2017; Nottingham and Larsson, 2018). Researchers have shown that learning goes through four stages. Students must go through productive struggle (the learning pit) to construct new knowledge (learning) (Nottingham, 2017). In going through these stages of learning, students of color not only have to resolve the cognitive conflict of sense-making (Nottingham, 2017; Nottingham and Larsson, 2018), but they must also contend with personal (e.g., stereotype threat) and systemic (e.g., structural racism) challenges to equitable learning (Aronson *et al*, 2009; Darling-Hammond, 2001; Delpit, 2006; Hammond, 2015; Pollock, 2017). As Carter Andrews and her colleagues noted (2019), schools often become inhospitable environments wherein students of color receive mixed messages and are held to unreasonable standards.

Consistent with survey data (Epstein *et al*., 2017) and literature on stereotype threat (Aronson *et al*, 2009), in-depth interviews of 70 high school girls showed that Black girls felt it necessary to off-set perceptions of being rowdy, disruptive, unintelligent, unmotivated, or some combination of these while feeling marginalized by their White peers and school personnel (Carter Andrews *et al*., 2019). Black girls and other marginalized students show significant social and emotional skills–including resilience (Rosen *et al*., 2010) and grit (Duckworth *et al*., 2007) when navigating inequitable spaces, but there is an exigent need to create equitable, supportive spaces for students to develop their academic, cognitive, social, and emotional growth in order to thrive (Darling-Hammond, 2001; Love, 2019).

BRIGHT-CS theoretical framework: A computer science learning ecosystem

The BRIGHT-CS student program created a learning ecosystem for middle school girls of color to experience computer science in an environment that reduces stereotype threat (Aronson *et al.*, 2009) and supports them through the learning pit to develop their academic, cognitive, social, and emotional growth (figure 1). The theoretical framework of BRIGHT-CS aligns with the social and emotional needs of middle school students (Delpit, 2006; Eccles *et al*., 1993) and started with a cohort of girls of color from the same middle school (grades 6-8). Across four key components of the program, the authors developed CS curricular materials and training materials focused on culturally responsive instructional practices, pedagogy, and collaborative activities (Hammond, 2015).

Figure 1: BRIGHT-CS program theoretical framework



For student outcomes, we defined CS/CT based on the K-12 Computer Science Standards (2017). Student activities and learning targets were aligned with the concepts of algorithms and programming across CS practices (Computer Science Teachers Association, 2017). An overview of the BRIGHT-CS components, CS standards, and student activities is shown in Table I.

Table I: Crosswalk of BRIGHT-CS program components, CS standards, and student experiences

BRIGHT-CS Components	K-12 CSTA CS Standards (2017)	Student Experiences
(1) School-based CS/CT experience: 9-month weekly after-school club **(2) Community-based CS/CT experience: 2-week summer camp**	• Collaborating around computing • Recognizing and defining computational problems • Creating computational artifacts • Testing and refining computational artifact	• Collaborated through small learning teams • Identified problems to solve using technology • Learned different coding languages to create and test shopping apps, games, art projects, and robots
(3) CT/CS career and entrepreneurial exploration **(4) Mentoring from CS professionals**	• Fostering inclusive community • Communicating about computing	• Presented computing artifacts to school leaders, parents, and mentors • Connected with mentors about CS careers

Methods

Following standards suggested by Levitt and her colleagues (2018), this section provides an overview of the research design, study participants and recruitment, data collection, and analysis.

Research design overview

The research team chose a mixed-method case study design focused on BRIGHT-CS participants across two cohorts (Baxter and Jack, 2008; Noor, 2008; Yin, 2009). A mixed-method design was implemented to better understand what works in terms of instruction and academic supports through the lens of lived student experience (Raudenbush, 2005). Quantitative data was collected before the start of the program via a student survey focused on computer science attitudes and compared with a national benchmark of students (Google Inc. and Gallup Inc., 2016).

Qualitative data was collected during and after program implementation via weekly observations, interviews, and computing artifacts to explore the context, phenomena, process, and potential causal explanations or theory (Denzin and Lincoln, 2018; Eisner and Peshkin, 1990; Garson, 2002; Leavy, 2015; Maxwell, 1998; Strauss and Corbin, 1990).

Study participants

Researcher description

The first and second authors are social scientists; they collected and analyzed qualitative and quantitative study data. The third and fourth authors are computer scientists; they validated the CS codes and themes used in the qualitative analysis.

The first author is Asian. The second author is a White Latina. The third and fourth authors are Black. All four authors are women of color; thus, they bring an intersectional lens to interviews with the students, parents, and other stakeholders. All authors have experience teaching students at the middle school, high school, or undergraduate levels. These experiences brought an educator's perspective to data collection, analysis, and interpretation.

Participant recruitment and selection

The first, second, and fourth authors began the recruitment and selection process for BRIGHT-CS by identifying a school sponsor at each of the four middle schools included in the study.

School sponsors recruited students and coordinated with parents to complete the program application and obtain active consent to take part in the study. All students who applied were accepted into the program. Ergo, one White male was admitted due to parent appeal to the principal; data from this participant was not included in this study, since the study focus was on girls of color.

Participant description

The study sample is composed of 53 students from four urban middle schools in the eastern United States. The students participated in the program during the 2018-2019 and 2019-2020 school years. The research team obtained parent and student consent to actively take part in the study. The 53 students account for 77% of the 69 students who applied and participated in the program.

The majority of the study sample were Black girls (66%), with 13% Hispanic, 11% White, and 11% Asian. Forty percent of the students (40%) self-reported that they spoke another language at home. The students spoke fluent English at school but other languages at home including Amharic, Bengali, Farsi, Haitian Creole, Hausa, Somali, Spanish, Tigrinya, Twi, and Urdu.

Data Collection

Quantitative data was collected on all 53 participants during the student application process. The student survey captured student demographics, perceptions of math and reading (NCES ELS, 2001), and experiences in CS (Google Inc. and Gallup Inc., 2016).

Qualitative data was collected during the BRIGHT-CS program activities and included interviews with students (N = 53), parents (N = 3), community mentors (N = 7), school staff sponsors (N = 4), school principals (N = 4), program instructors (N = 3), and summer program instructors (N = 3) at multiple time points during the program. In addition to the interviews, we also collected program documents, computing artifacts, weekly observations of after-school sessions, and daily observations of summer sessions.

Analysis

Quantitative data were analyzed using descriptive statistics. Qualitative data were digitized, uploaded to DeDoose (a cloud-based qualitative analysis platform), and analyzed using a" start list" (Garson, 2002; Hill *et al*., 1997; Leavy, 2015; Saldana, 2009). The start list was based on the main components and theoretical framework of the project and finalized into core ideas, themes, and cross-analysis (Garson, 2002; Huberman and Miles, 1994; Leavy, 2015; Strauss and Corbin, 1990). The research team met to finalize coding (reaching 100% agreement on data coding), triangulate data and data findings, and confirm the consistency of results across cohorts and respondents.

Results

We found that students in the BRIGHT-CS program had higher interest (36%) and higher confidence in their ability to learn CS (68%) than a national sample of 771 girls (16% and 48% respectively) (Google Inc. and Gallup Inc., 2016). Almost 2 in 3 students in the program were told by their teachers and parents that they would be good at computer science (60% for both teachers and parents), compared to about 1 in 4 girls in the national sample. Differences are not surprising given that, unlike the national benchmark sample, students in the program self-selected to participate in a CS program. Reasons that motivated students to join the program included wanting to learn something new (43%), having a passion and love of computer science (30%), and seeing CS as a useful skill for future careers including non-STEM careers (26%). However, high interest, confidence, and motivation were not enough for students to fully engage in and learn CS.

We observed two types of learning behaviors during the implementation of BRIGHT-CS– dependent learning behaviors (exhibited by students dependent on the guidance of the instructor at each step of the aforementioned learning process) and independent learning behaviors (exhibited by students moving independently through the learning process, without extensive guidance or support from the instructors) (Delpit, 2012; Hammond, 2015). We identified 10 girls who–despite their self-reported confidence–began the program as dependent learners and another 10 who began as independent learners. We found that the CS learning ecosystem supported student engagement via developing independent learning behaviors. We will first provide a description of Sara, a 6th grader in the program, that highlights the core themes of how students engaged in and learned CS.

The story of Sara

Like many students in the BRIGHT-CS program, Sara rated herself as having “high interest” and “high confidence” in learning CS. Sara had prior exposure to CS through elementary school coding experiences (i.e., after-school clubs and summer camps), watching her older brother code at home, and encouragement from her parents to become a computer scientist in the future. Sara stated:

> My mom sort of started getting me into coding and computer science and stuff. She was like, “In your future you could become a computer science person and code robots!” At the beginning, I felt like I had to do [CS] because my mom was telling me to. But then when I got to know coding and stuff, I was like, “It’s pretty interesting and fun.”

Despite Sara’s interest, confidence, and family support for CS, at the beginning of her year in BRIGHT-CS, she was anxious to avoid drawing attention to her CS skills (or perceived lack thereof). This resulted in behaviors counterproductive to Sara’s learning. She barely spoke to her instructor and peers, giving halting answers or shutting down with her head down when asked even the most basic questions. After a group brainstorm of ideas for an internet application development project, she remained silent when the instructor asked her to share her ideas, even when the other girls encouraged her. Often, she sat inactive next to her partner during independent work time until the instructor intervened to help them with the task.

By the end of the first semester, she spoke positively about the experience of working with partners whom she'd gotten to know during the program. However, she remained reluctant to answer questions in front of the whole group and still spoke tentatively about her CS skills. "I'm new to the things we're learning here," she said, "but I'm gradually learning, I guess." Yet she re-enrolled for a second semester, even convincing her twin sister to join her. Eventually, she began volunteering ideas during group brainstorms and answered instructor questions without prompting.

By the last session, she volunteered answers to questions even after answering one wrong in front of the whole group. Earlier in the program, she stated that she would only raise her hand when, "I know for sure that this is the answer." Now she was willing to "take chances." Once, while coding independently, she said aloud to herself, "That won't work," and–when the instructor asked her why not–promptly diagnosed her error in front of the whole group. She also stopped relying on the instructor to troubleshoot problems and started resolving challenges on her own. She even began assisting her peers when they encountered roadblocks in their own work.

When asked, Sara attributed her changing comfort and engagement levels to the fact that the second semester curriculum built on concepts and skills she'd learned in the first semester. She was more confident in her knowledge because, "I've done this stuff before." She also said the instructor made her feel "comfortable" speaking even when she didn't know the answer. The instructor built trust with Sara by asking her questions privately, "…while other people are working, not paying attention… So, like everybody wasn't focusing on me." If the one-to-one conversation surfaced a misconception, the instructor would normalize it by clarifying the concept for the whole class. Eventually, not knowing seemed like a part of the process, rather than something for which Sara might be judged.

The instructor stated that Sara became more comfortable when the program curriculum shifted toward building skills for a long-term capstone project, i.e., developing a web application. This relieved pressure on students to acquire new skills quickly. With the longer focus, students weren't told, "You need to learn this by this time; you need to learn that by that time." Students avoided becoming "overwhelmed at having to learn so much," in a short period of time. Sara now had the time and flexibility to productively struggle with the CS content. The instructor also reassured students that struggle was a normal part of the learning process. This reassurance reduced Sara's anxiety around potential public humiliation and promoted the development of independent learning behaviors.

By the end of the program, Sara exhibited leadership behaviors. She began assisting other students who were struggling, worked with the instructor to show other students how to code or debug a program, and helped recruit other girls of color to participate in the program. As she reflected on the program, she stated how she used to watch her brother code at home. Now, she knows that she can do it too.

Discussion

The story of Sara and her growth toward exhibiting independent learning behaviors highlights the time and care it takes to support student learning. In this case, the year-long CS learning ecosystem involved over 130 hours of the following instructional features that supported engagement in CS/CT via independent learning behaviors.

Theme 1: Problem solving – "Give us space to figure stuff out for ourselves"

A major component of CS is framing problems in a way that a computer or other technologies can be used to solve them (CSTA, 2017). We found that independent learners enjoyed problem solving, especially when given the time and safe space needed for productive struggle (e.g., trial and error). During program observations conducted by the researchers, Sara said to herself, "That won't work" and continued to problem solve.

As the capstone project came into focus for the students, most of the independent learners indicated they were eager to jump in and learn by “figuring it out” on their own (n = 8). One independent learner said, “They give us a lot of space to figure stuff out for ourselves, which is really nice. [It’s] unlike school where you watch videos of people doing it and you don’t really get to experience doing it. Here, we can actually try stuff instead of just looking at [teachers] doing it.”

In contrast, dependent learners were less inclined to pursue new skills or knowledge on their own. They only engaged if asked to reproduce instructor-modeled skills or knowledge without deep cognitive effort. Dependent learners would often answer simple recall questions or follow an instructor’s step-by-step procedures (n = 5), but they were more likely than independent learners to stop working on their products when continuing to improve them would require independently honing new skills. Hammond (2015) indicates that this “learned helplessness” is rooted in students’ beliefs that they do not have the capacity to improve.

Students’ beliefs about what it means to master new skills and knowledge (i.e., “to understand”) differed according to their preference for “figuring it out” or reproducing instructor procedures. Independent learners were much more likely than dependent learners to associate understanding with knowing why or how something “works” (n = 8). Dependent learners were more likely to associate understanding with being able to name and remember the steps for completing a task (n = 3).

One dependent learner said that math was her favorite subject in school “because you just memorize stuff” and another said that “math is pretty easy to me”, because “once I understand the method, it’s pretty easy to move on.” This stands in contrast to an independent learner who complained about feeling like “I don’t understand” in math class because “I just know [the steps] to do it. I don’t know why [the steps work].” A few dependent learners did express frustration with the limits of procedural learning, if not an awareness that the methods they favored for learning could be to blame.

Two dependent learners–who dutifully engaged when BRIGHT-CS instructors invited them to follow along with a coding demonstration–admitted in interviews to feeling that their understanding remained low. One dependent learner said, "[I'm] typing random words that don't make sense." Another stated that ,"I might change my mind if I actually understood how to code, but right now I'm just seeing a bunch of words." This suggests that dependent learners may desire the deeper learning that comes from "figuring it out" themselves, but they gravitate towards procedural learning. This could be an indicator that they have yet to develop the cognitive strategies or social-emotional skills to embrace opportunities for trial-and-error and other strategies that independent learners prefer to use in STEM+CS.

Theme 2: Iterations – "I decided to improve it"

Another important skill in CS is iterating, being able to update and improve products (CSTA, 2017). We found that independent learners were never "done" with their projects, almost to the annoyance of dependent learners during collaboration. Independent learners sought new ways to improve their design, program, or computing artifact. Sara was even known to bring computing artifacts home to continue working on improvements.

In BRIGHT-CS, projects were often designed to allow for some choice in the content, functionality, and visual presentation of the final product. Dependent learners engaged in those aspects of their product where they already had skill, such as in perfecting the visual presentation of their product, rather than working on aspects of the project that challenged them to develop new skills, e.g., coding (n = 4). When working on a project to design and program a robot, one student explained that she chose a "simplistic" robot because, "I didn't want to drive myself crazy with coding." Once the robot had basic functionality, she was eager to move on from learning CS to applying her artistic skills to "make [the robot] pretty." When working in groups, dependent learners sometimes even avoided intellectual labor around the computing aspects of their product entirely, forcing others to carry the cognitive load.

By contrast, independent learners were more likely to spend their time developing new skills in order to make improvements to their product (n = 6). One student who designed a functioning robot to turn her bedroom light switch on and off said, "Now I'm trying to figure out how to not attach [it] to the computer…so I don't have to carry the computer with me… To add it to mobile devices had a lot of complicated stuff, but it's going to help me."

Another difference between independent and dependent learners involved how students decided their products were "finished" and, subsequently, that it was time to stop working. Because students determined the features and functionality of their project, the decision as to when their product was "finished" was largely theirs to make. Both dependent and independent learners found that integrating additional functionality into their product would require CS skills or knowledge beyond the basics that the instructor had taught the whole class. In instances like these, dependent learners were more likely to declare their product "finished" when it had yet to perform all of its intended functions, rather than work independently to develop the additional skills and knowledge they would need (n = 3).

One dependent learner who originally planned to make her product compatible with a mobile device (much like the independent learner described above), said that "[i]n the beginning I had a whole plan to connect it to the phone. But I don't have the stuff and my brain is not that high." She subsequently abandoned the mobile aspects of her product. By contrast, independent learners were less likely to stop working or declare their product "finished" when there were still improvements to make, even when they had to explore new CS skills and knowledge on their own. "I thought I was done a little while ago because [my product] was working," one student said, "then I decided to improve it with different wiring."

Theme 3: Debugging – "It's actually kind of fun"

A third component of CS skills is debugging or identifying and fixing errors in a program (CSTA, 2017). While we found that both independent and dependent learners ran into challenges while working on their projects, the strategies they used to get themselves "unstuck" varied significantly. Sara provided a good example of how debugging could initially be anxiety-provoking. At one point she stated, “At first, I thought [Python] was really hard, and it was complicated. I would just try to think about the easy stuff and then try to do that so that I could encourage myself”. However, towards the end of the program, she would “take chances” and openly present her mistakes and the various strategies she used to fix her code.

Dependent learners were more likely to request help from instructors as their primary debugging strategy (n = 4). One dependent learner described the frustrating experience of losing her prior day’s coding because, “It didn’t save like I wanted [and] I don’t remember what to do.” Rather than try to recover her code using her own strategies, such as working together with classmates who’d also participated in the prior day’s coding lesson, she relied on the instructor to “show the whole class how to do it again.”

Independent learners also asked instructors for help, but they were much more likely to tackle challenges on their own by creating a plan of attack, rereading instructor-provided materials, conducting their own research, focusing on the easy parts first, or using trial and error (n = 10). One independent learner said, “Help wasn’t always available. I had to figure out what I did wrong, how to fix it, and not make the same mistakes again–hrough trial and error and applying what I already knew. That’s something I just kind of do [in all my classes].” Some independent learners even said that solving their own problems using trial and error was ultimately more instructive or satisfying than calling on instructors (n = 3). “I just kept trying new things, even though sometimes I knew it wasn’t going to work. I still wanted to try. Because it’s a trial-and-error process and it’s actually kind of fun.”

Conclusion

The study looked at the effects of a CS learning ecosystem on 53 girls (grades 6-8) and their engagement, learning, and persistence in CS. The study found two main results. First, for students to engage, learn, and persist, students need to practice independent learning behaviors; that is, students moving independently through the learning process without extensive guidance or support from the instructors. Second, for students to practice such learning behaviors, educators need to create an optimal learning environment that focuses on key CS principles such as problem solving, iterations, and debugging.

Prior research has shown the importance of persistence through grit (Duckworth et al., 2007), growth mindset (Dweck, 2006; Haimovitz and Dweck, 2017), and self-affirmation (Binning et al., 2019; Harackiewicz et al., 2016) for student learning. While students reported that they were highly interested and very confident in learning CS, our results highlight the importance of purposefully and explicitly developing students' independent learning behaviors. Students need a sustained focus on growth mindset as they go through the learning pit, with educators actively developing and nurturing independent learning behaviors.

We found that moving from dependent to independent learning behaviors does not occur in a vacuum or naturally. For equitable learning experiences, it is necessary for instructors and educators to explicitly model, teach, and coach students within a safe and patient learning environment (Darling-Hammond, 2001; Hammond, 2015; Oakes, 2005). To do so, instructional practices that highlight computational thinking, such as problem solving, iterations, and debugging, can lead students into a growth mindset and thus learning.

Implications for Future Research

While the study focused on a CS learning ecosystem (i.e., BRIGHT-CS) and CS engagement, learning, and persistence, future research should include applying the ecosystem approach to other subject areas with a disconnect between student interest and student outcomes. Similar to CS, Black students had the highest percentage of reporting confidence in their ability to excel on mathematics tests (70%) and certainty that they can master mathematics skills (77%), higher than Asian (68% and 74%), Hispanic (65% and 71%), and white (65% and 68%) students respectively (National Science Board, National Science Foundation, 2019). Yet, Black students had the lowest rates of taking AP math or science courses and exams, ranging from 2-7%, compared to White (45-56%), Asian (13-34%), and Hispanic (9-22%) students. This disconnect between student confidence and interest with student access and opportunity is indicative of inequitable systems, not deficits in students. More nuanced research is needed to identify and rectify gaps in the system, not gaps in students, by bringing computational thinking practices into educational equity.

Limitations to the study

There were two main limitations to the study. First, the study focused on those students who were a part of the program and did not utilize a comparison group of girls who did not participate in the program. As a result, we cannot compare differences in student outcomes between a treatment and comparison group of students. Second, the study collected data across two school years (2018-2019 and 2019-2020) wherein implementation of the program not only varied across the four middle schools, but the 2019-20 cohort of students was not able to finish the program when schools closed on March 2020 due to the COVID-19 global pandemic.

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Author Bios

Dr. Ryoko Yamaguchi is a social scientist with expertise in research design and methods, school and educator improvement, and educational equity. She has been studying how schools can serve as a protective factor for at-risk youth for over 25 years. Her research focus has led to several researcher-practitioner partnerships supporting educators to become active designers of equity. She is the lead author of Adaptive Implementation: Navigating the School Improvement Landscape (2017).

Veronica Hankerson Madrigal is an experienced qualitative researcher specializing in education policy research. She began her career working in DC Public Schools as a teacher and district staff member. Her research experience runs the gamut from conducting classroom observations and interviews for large scale evaluations; producing literature reviews, case studies and landscape scans; and leading qualitative analysis of student and educator interviews.

Dr. Jamika D. Burge is a computer scientist, design executive, and entrepreneur with expertise in human-computer interaction, design thinking, and curriculum development. She specializes in ideating, creating innovative user research, and designing learning curricula and experiences that empower students and professionals alike to apply a lens of inclusion and humanity to their daily work and beyond.

Dr. Cyntrica Eaton is a computer scientist with expertise in software development, software testing and curriculum design. Navigating academic and professional computer science and computer engineering spaces for over 20 years, she has first-hand understanding of the need for more people of color in these fields. For the past 13 years, a key aspect of her professional focus has been designing, implementing, and evaluating supports for more equitable STEM+CS practices and policies.