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Equitable STEM+CS learning experiences for girls of color: Nurturing an independent learning approach via a learning ecosystem

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, between the ages of 11 and 13, in four United States middle schools. Study methods included the analysis of a pre-program student survey, 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 applying dependent learning approaches to applying independent learning approaches. 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 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, we studied the design and implementation of a CS learning ecosystem that supports middle school girls – between the ages of 11 and 13 – and Black girls in particular in acquiring computer science and computational thinking (CS/CT) skills. The ecosystem is a comprehensive yearlong CS learning experience that includes culturally responsive CS curriculum materials with career exploration that highlights the achievements of Black women in technology; Black women computer scientists serving as instructors and mentors who were trained in culturally responsive and equitable instructional practices; weekly CS experiences at school; and two-weeks of summer camp at a local university.

Our guiding research question focuses on the CS learning ecosystem, and asks: How does the experience of a CS learning ecosystem (re)shape students' perceptions of and behaviors towards CS engagement, learning, and persistence? To explore this question, 53 middle school girls from four urban middle schools in the eastern United States were engaged in the study. Pre-program data on student demographics, perceptions of math and reading, and experiences in CS were captured and analyzed quantitatively. During and post-program data from observations, interviews, and computing artifacts were coded and analyzed qualitatively to understand students' CS engagement, learning, and persistence.

Literature Review

Within the context of adolescent development, students experience dynamic physical, social, and cognitive changes (National Academies of Science Engineering and Medicine, 2019), their schooling experience also changes as coursework becomes more rigorous, teachers' expectations change, class schedules become more intense, and parent role expectations change from more to less involved (Eccles et al., 1993).

Girls of color are met with additional identity formation challenges as well. Their development includes a "racial puberty" (Kendi, 2019; Umana-Taylor et al., 2014) which involves making sense of their racial and gender identities and navigating through experiences of stereotype threat (Steele & Aronson, 1995), imposter syndrome (Clance, 1985; Clance & Imes, 1978), and explicit and implicit biases (Epstein, Blake, & Gonzalez, 2017; Young, Young, & Ford, 2017). Yet there is a further challenge for girls of color, they are underrepresented in advanced and gifted classes at school (Grissom & Redding, 2016; Shores, Kim, & Still, 2020; Young, Young, & Ford, 2017) and in STEM+CS focused activities (Hill, Corbett, & St. Rose, 2010; McGee, 2013; Ong et al., 2011; Young, Young, & Paufler, 2017).

To better support the engagement, learning, and persistence in STEM+CS of girls of color, culturally responsive learning environments should actively develop belonging and STEM identities, support girls through the productive struggle of learning, and to nurture independent learning behaviors and approaches.

Developing belonging and STEM identities.

Past research has shown the importance of improving K-12 STEM learning experiences for girls of color by creating culturally responsive learning environments that foster deep engagement, learning, and persistence (Calabrese Barton, 2019; Farinde & Lewis, 2012; Kang *et al*., 2019; King, 2022; King & Pringle, 2019). Deep engagement, learning, and persistence are rooted in developing a sense of belonging and building STEM identities in formal and informal spaces (Kang *et al*., 2019; King, 2022; King & Pringle, 2019; Ireland *et al*., 2018; Ong *et al*., 2011).

STEM disaffiliation, particularly for girls of color, can be seen as early as elementary school with Black girls not wanting to be identified as a "smart science student" (Carlone, Haun-Frank, & Webb, 2011). However, proactively developing culturally affirming STEM identities serves as a foundation for STEM interest and career exploration (Calabrese Barton et al., 2013; Calabrese Barton et al., 2008; King & Pringle, 2019).

Supporting productive struggle of learning.

Providing culturally responsive learning environments involves helping students navigate learning challenges and resolving productive struggle (Nottingham, 2017; Nottingham and Larsson, 2018). Students must go through productive struggle to construct new knowledge, that is, learning (Nottingham, 2017). However, 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).

Carter Andrews and her colleagues noted (2019) that 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 offset 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. However, culturally responsive learning environments create equitable, safe, and supportive spaces for students to practice productive struggle for deep engagement and learning to take place (Darling-Hammond, 2001; Hammond, 2015; Love, 2019).

Nurturing independent learning behaviors and approaches.

Delpit (2006, 2012) and Hammond (2015), grounded by the works of Ladson-Billings (1995, 2017), have noted that "good teaching" is more than just relaying academic content. Culturally responsive learning environments are about explicitly and proactively nurturing the learning capacity of students (academic, cognitive, social, and emotional capacity) (Delpit, 2006, 2012; Hammond, 2015; Ladson-Billings, 1995). While younger students are dependent on their teachers to learn developmentally, adolescence is a time when effective pedagogy includes developing students' independent learning behaviors. Adolescent students are expected to become less dependent on the teacher and more independent as they learn to scaffold learning (Hammond, 2015).

Students of color and other marginalized students are often not taught skills needed to move from being dependent to independent learners (Allington and McGill-Franzen, 1989; Darling-Hammond, 2001; Delpit, 2012; Hammond, 2015). Thus, there is a critical need to systemically, consistently, and proactively support girls of color to develop culturally affirming STEM identities, successfully engage in productive struggle, and practice independent learning behaviors and approaches to engage, learn, and persist in CS (Scott, Sheridan, & Clark, 2015).

BRIGHT-CS theoretical framework: A computer science learning ecosystem

The Building Student Retention through Individuated Guided coHort Training in Computer Science (BRIGHT-CS) student program created a CS learning ecosystem for middle school girls of color to experience CS in an environment that supports their STEM+CS identities, helps them navigate through productive struggle, and helps them learn skills necessary to develop learning independence. 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 and ages 11-13). 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).

Insert figure 1

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.

Insert table I

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). We implemented a mixed-method design to better understand what works in terms of instruction and academic supports through the lens of lived student experience (Safir & Dugan, 2021). Quantitative data were 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 were 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 reviewed the CS artifacts and validated the CS codes and themes used in the qualitative analysis.

The first author is Asian. The second author is White Latina. The third and fourth authors are Black. All four authors are women of color; thus, they bring first-hand knowledge of the subtle inequities in the learning system. The intersectional lens and identities of the research team supported candor and openness during interviews with students, parents, and other stakeholders. All authors also have experience teaching students at the middle school, high school, or undergraduate levels, bringing an additional 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, prioritizing recruiting Black girls, 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 the sample or the analysis since the study focuses on girls.

Participant description

The study sample is composed of 53 girls 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 53 girls account for 77% of the 69 students who applied, participated in the program, and gave active parental consent and student assent to take part in the study.

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 were collected on all 53 participants during the student application process, pre-program. 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 were collected during and post-program 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 and after the program. In addition to the interviews, we collected program documents, computing artifacts, weekly observations of after-school sessions, and daily observations of summer sessions. Observational and interview data were prioritized during and post-program in order to capture behaviors rather than attitudes of student engagement, learning, and persistence in CS.

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 frameworks of the project, with initial codes for student engagement, learning, and persistence behaviors during the in-school, summer, and mentoring experiences; student experiences with peers; and instructor instructional approaches and rapport building with students.

Codes were further refined via triangulation with pre-program survey data; computing artifacts; and instructor, parent, and stakeholder interviews. Codes were finalized into core ideas, themes, and cross-analysis with validation from the program instructors (Garson, 2002; Huberman and Miles, 1994; Leavy, 2015; Strauss and Corbin, 1990), with 100% agreement on data coding across cohorts and respondents.

Findings

By analyzing the pre-program survey data collected from participants, 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.

Students indicated that they joined the program to learn something new (43%), because they have a passion and love of computer science (30%), and they see 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 behavior approaches during the implementation of BRIGHT-CS–dependent learning approaches (exhibited by students dependent on the guidance of the instructor at each step of the aforementioned learning process) and independent learning approaches (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 applying dependent learning approaches and another 10 who began with independent learning approaches. We found that the CS learning ecosystem supported student engagement, learning, and persistence by igniting and strengthening independent learning approaches. To highlight the core themes of how students engaged in and learned CS, we will focus on the experience of Sara (a pseudonym), a 6th grader in the program.

The Story of Sara

Sara's story demonstrates how a culturally responsive learning environment (i.e., BRIGHT-CS herein), supports deeper engagement, learning, and persistence. Sara's growth and adoption of independent learning approaches embodied the growth seen in other students as well. Sara persisted by completing and presenting her computing artifacts. She also continued to participate in the second year of the program and recruited other girls to join her. Sara's experience (i.e., her adoption of independent learning approaches that include freely engaging in open-ended discussion and resolving challenges with minimal guidance) underpins the broader themes of becoming more comfortable participating in productive struggle, iterating to maximize outcomes even when it requires learning new skills, and creating a strategic plan to 'debug' errors while programming and designing.

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 engagement and learning. She barely spoke to her instructor and peers, giving halting answers or putting 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 and recruiting additional girls into the program. 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 reinforced 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. In a parent interview at the end of the program, her mother stated, "I'm glad you can see the Sara we see at home." 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.

Key Themes

The story of Sara and her growth toward exhibiting independent learning behaviors highlights the time, patience, 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 to create a culturally responsive learning environment that supported engagement in CS/CT via independent learning behaviors and approaches.

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 students who primarily applied independent learning approaches 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, most of the students primarily applying independent learning approaches indicated they were eager to jump in and learn by "figuring it out" on their own (n = 8). One student who used an independent learning approach 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, students who applied dependent learning tactics 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. Students who primarily applied a dependent learning approach would often answer simple recall questions or follow an instructor's step-by-step procedures (n = 5), but they were less likely than students with independent learning tendencies to continue working on their products when doing so required 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. Students with independent learning tendencies were much more likely than their peers to associate understanding with knowing why or how something "works" (n = 8). Students who primarily applied a dependent learning approach were more likely to associate understanding with being able to name and remember the steps for completing a task (n = 3).

One student with dependent learning behavior tendencies 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 students who were primarily independent learners 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 students who were primarily 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 students who were primarily 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 such student said, "[I'm] typing random words that don't make sense." Another stated, "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 students who primarily exhibit dependent learning behaviors 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 students who primarily apply an independent learning approach 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 students who were primarily independent learners were never "done" with their projects, almost to the annoyance of their dependent-learning peers during collaboration. Independent learning students 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. Students who were primarily 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, students who primarily apply a dependent learning approach sometimes even avoided intellectual labor around the computing aspects of their product entirely, forcing others to carry the cognitive load.

By contrast, students who primarily apply an independent learning approach 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 learning approaches 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) to complete their project.

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.

Students who exhibited dependent learning behaviors 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–through 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."

Discussion

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, moving independently through the learning process without extensive guidance or support from the instructors by focusing on key CS principles such as problem solving, iterating, and debugging.

Second, for students to practice such behaviors, educators need to actively foster culturally responsive learning environments that create hybrid spaces for students to develop STEM+CS identities, support girls through the productive struggle of learning, and to nurture independent learning behaviors and approaches.

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) to 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. To bridge the gap between high student interest in CS and low representation and participation in CS pipelines, students need a sustained focus on growth mindset as they go through the learning process, 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 and intentionally model, teach, and coach students within a safe and patient learning environment (Darling-Hammond, 2001; Hammond, 2015; Oakes, 2005).

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. For example, 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 (National Science

Board, National Science Foundation, 2019). This disconnect between student confidence and interest with student access and opportunity is indicative of inequitable systems, not deficits in students. More nuanced research with critical interrogation of assumptions and interpretation of data is needed to identify and rectify gaps in the system, not deficits in students.

Future research should also explore how the independent learning behaviors and approaches can be applied to other learning experiences and across disciplines. More research is needed to understand whether the independent learning approach is specific to CS, with learning and applying computational thinking principles such as iteration, debugging, and abstraction, or whether this type of learning approach can be taught and supported in other STEM fields.

Limitations to the study

There were three 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. 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 shifted to online learning in March 2020 due to the COVID-19 global pandemic. Finally, quantitative survey data of interest and attitudes towards CS was only captured at baseline (pre-program) because the study design prioritized measuring observable CS behaviors via qualitative coding; as a result, quantitative analysis of changes in CS attitudes were not prioritized in the study design.

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Figure 1: BRIGHT-CS program theoretical framework

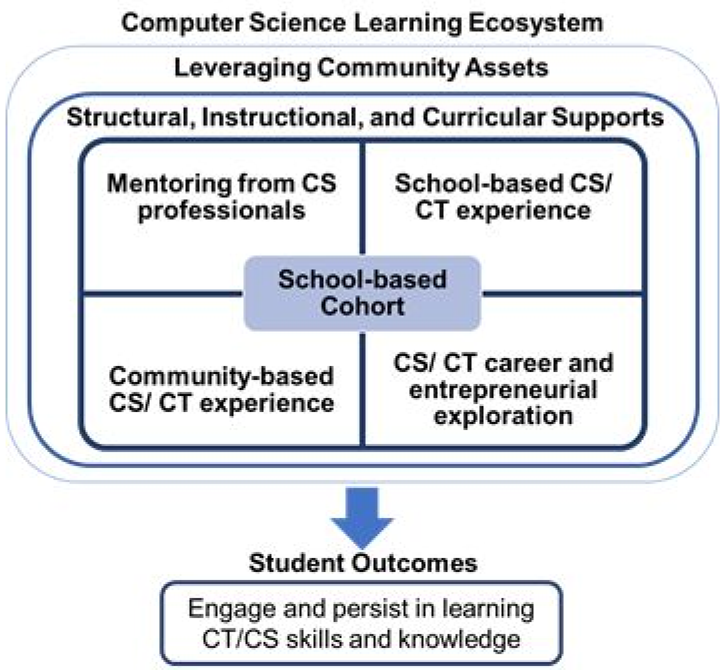

Table I: Crosswalk of BRIGHT-CS program components, CS standards, and student experiences

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