Seamfulness and Culturally Responsive Computing

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***Abstract*—To make computer science (CS) more equitable, many educational efforts are shifting foci from access and content understanding to include identification, agency, and social change. As part of these efforts, we look at how learners perceive themselves in relation to what they believe CS is and what it means to participate in CS. Informed by three design lenses, *unblackboxing, culturally responsive computing*, and *creative production*, we designed a physical computing kit and activities. Drawing from qualitative analysis of interviews, artifacts, and observation of six young people in a weeklong summer workshop, we report on the experiences of two young Black women designers. We found that using these materials young people were able to: leverage personal goals and prior experiences in computing work; feel as if they were figuring out computing systems; and recognize computational technologies as created by people for particular purposes. We observed that while the mix of materials and activities created some frustration for participants, it also prompted processes of community building and inquiry. We discuss implications for design of computational tools in equity-centered CS education and pose *seamfulness* as an emergent heuristic when designing for learning that engages young people with the social, not just material, systems of computing.**

Keywords—physical computing, culturally responsive, creative computing, design, competency belief

I. Introduction

Our project aims to facilitate new kinds of participation in CS education to support young people – particularly young Black and Latina women – to both persist in *and* change CS [1]–[3]. Drawing from creative computational work [4] and culturally responsive computing [5], we facilitated activities that use a kit of tangible, modifiable components that work with widely available microcontrollers. The kit was designed to be easy to use, make multiple aspects of computing visible, and allow learners to connect computing to existing areas of interest and expertise. Using expressive crafting and physical computing to put stories at the center, we aim to shift what young people believe they can do in and with CS. We asked, 1) how do experiences with creative, tangible computing influence young people's perceptions of what they are capable of and what computing can be? and 2) What aspects of kit materials and activities are associated with these perceptions?

Outcome Lens: As a near-term lever for supporting longer term trajectories in and with computing, we focused in this study on young people's perceptions of themselves and of CS. At the project outset, we framed this with the construct of *competency beliefs*, beliefs learners hold about how likely they are to succeed in a particular domain. Especially for young women, competency belief has been shown to be a predictor of learning and future participation in STEM fields that is amenable to intervention [6]–[9]. A component of competency belief known as *outcome expectancy* also speaks to one way power reproduces inequality by suppressing a belief that one's actions will be recognized, legitimized, and rewarded [10]. In CS, this happens directly by discouraging or disallowing people to join or contribute to computing experiences, as well as indirectly through expectations of teachers and peers [11], [12], and cultural narratives of who technologies and computing experiences are meant for [13]. Therefore, central to this study is a relationship between *perception of self* and *perception of computing*, including perceptions of how interesting, challenging and socially valued CS is, and how participants believe they will be viewed within CS communities.

Design lens: To open new possibilities for interaction, facilitation, and computational production, we designed a physical computing kit and supporting activities, drawing on research in three areas: unblackboxing; expressive craft; and culturally responsive computing. *Unblackboxing* makes visible and modifiable key aspects of computing systems [14]–[16]. *Creative, expressive crafting* helps youth engage in computing as personal and purposeful by utilizing familiar materials in new ways and allowing objects to be shaped by young designers' aesthetics and existing expertise [17], [18]. Principles for *culturally responsive computing (CRC)* include positioning young people as experts and using designers' identities and narratives as drivers of computational production and inquiry [4], [5]. Research in CRC highlights the importance of connecting computing concepts to everyday life [19] and interrogating the values "baked into" technologies [20], [21].

Analytic Lens: To understand young people's experiences with the kit and activities, we draw from situated theories that examine learning as people work toward relational and intellectual goals within social and cultural contexts [22], [23]. We analyzed both participant narratives and interactions, foregrounding young people's sense-making within social and material interaction [24]. This dual lens allows us to be sensitive to how participants' goals for and understandings of CS learning connect to personal experiences and identities, while also being sensitive to change over the course of participation, with moments of discovery, frustration and revisioning.

II. Methods

In this study, three young men and three young women (ages 11-14) participated in a free, 5-day online workshop. Students joined from a large southern US city and a smaller city about 3.5 hours away. All the young designers identified as Black. The two primary instructors were a White, woman middle

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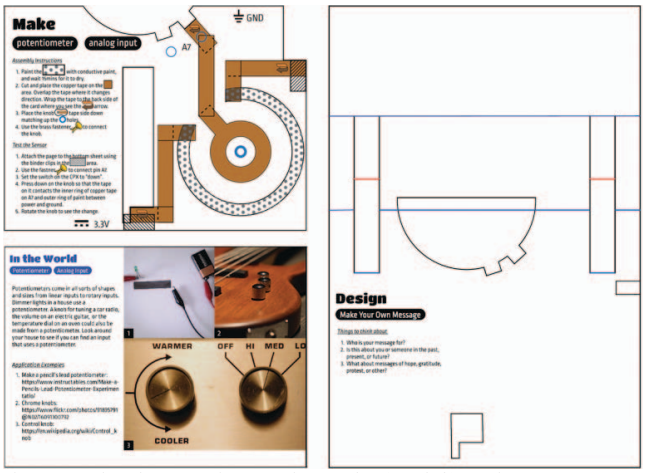

Fig. 1. Cardstock computing "cards": Make (top left) cards support sensor creation; Design (right) cards scaffold expressive design tasks and can be layered on top of Make cards; In the World cards (bottom left) show everyday uses of physical computing.

school educator and a Black woman who is a graduate design student. Two educational researchers, a Chinese American woman and White man, and a Korean woman HCI designer and researcher were participant observers. Materials, including microcontrollers, were sent to participants.

In the workshops, youth were introduced to computational making and invited to create three projects – *Message*, *Map*, and an open-ended final project. The kit uses a Circuit Playground Express microcontroller (CPX), printed cardstock (Fig. 1), copper tape, and other conductive and craft materials. In each project, the designers brought together their unique ideas and newly learned practices to investigate CS *concepts*, such as sensor inputs, outputs, conductivity and resistance, and *practices*, like testing, debugging, and interaction design.

The research team collected observations, documented youth-created artifacts (captured via Zoom) and conducted one-on-one interviews at the end of the workshop and again five weeks later. A short survey, based on prior competency belief instruments, also informed analysis. Interviews were transcribed and coded, along with field notes, memos, and photographs of youth projects. Coding began with deductive and emergent categories that were refined across multiple rounds of analysis [25]. In analysis we sought to understand how each participants' experience differed, while also articulating themes present for a majority, if not all of them. We report on two cases that are unique in the particulars, but illustrate these common themes [26].

III. Results

Below, we describe the experiences of two young Black women, RMA and KH, focusing first on their workshop projects, then on reflections from interviews. We organize our report around ways that we saw perceptions of self and computing take shape during the physical computing workshop.

A. RMA & KH's Projects

RMA participated in the workshop along with her twin sister, RJA. Their mother had signed them up for a STEM camp earlier in the summer, in which they did bottle rockets and robots, and RMA figured she would try something else similar. Unlike RJA, RMA had not previously been interested in CS or electronics, declaring to us her interest in art and video. RMA and her sister were two of the most vocal members of camp. They were quick to engage in computational work, collaborative activities, and sharing out reflections and stories. For her first "message" project, RMA was inspired when she found a key in her room, during an activity to find conductive materials in your home (Fig. 2). She said:

> I decided to do it [depression] because I was, um, I wanted to use keys in my project because they were very conductive. And so I thought maybe I can use some locks and use some keys and that could symbolize, like, depression [and that] with every problem there's a solution. And there's always a way out… And it's actually important to me because like, it's a part of mental health and a lot of people have it cause - like all around you.

As she learned more, RMA was intrigued by the aesthetic possibilities of the DIY potentiometer, despite or perhaps because of the conductive paint they received smelling like "turtle water," as another participant aptly observed. Moving to the Map project, RMA increased her skill with circuit design and started noticing new aspects of computational behavior, such as intensity of the light changing. However, the Map project template did not include places she had visited before and so did not represent her experiences in a meaningful way. In thinking about what she would do for a final, less scaffolded project, she decided to do something playful and personal, creating a "SirenHead" character from a fan-produced horror film. She constructed circuits and large cardboard structure from scratch, while re-coding the CPX to match the character.

Due to scheduling conflicts and poor internet connection, KH missed some of the introductory sessions. She was less vocal than RMA and was often offline or off-camera. Without the eyes-on support that instructors could provide to those with better connectivity, KH was often catching up with projects, but worked hard on the sensors and thought deeply about what she wanted to do with them. Like RMA and many of the other participants, she was initially frustrated by copper tape and took time after the workshop hours to get her circuits "perfect." Yet she talked about liking using the tape to "put things together," and appreciated the novel materials:

> [Most interesting to me] was the fact that it was on paper and cardboard - that I didn't know what it was going to do because I didn't think it would be on paper. I thought it'd be on like, something digital or like – I love to take apart things. I get in trouble for it, but like all the little toys and stuff, I used to take them apart and just look inside of them. So I thought it would look something like that, but it was paper. So that was new. And it was like, I was wondering how it was going to work. How it was going to connect and what it was going to look like.

For her final project, KH was inspired by the CPX lights to speak to an issue she cared deeply about, foster care:

> With sexual assault and everything, it is hard… when you said we were going to be using lights, I thought of an idea

Fig. 2. RMA's "Message" project, integrating into her sensor circuit a key found in her home as a metaphor to dealing with depression.

with foster care. I didn't know what I was going to do yet. But then that gave me an idea to use that in the process.

Though her project made use of CPX's built-in LEDs, KH went well beyond the kit as we sent it, creating intricate paper cuts, using tape and cardboard from around her house, and engineering a layered three-dimensional landscape to tell a story that was important to her.

B. Sense of Accomplishment in Computing

Both RMA and KH reflected on how work with the kit and activities created a sense of accomplishment and connection: an ability to figure things out, see what you're doing, and see progress you are making. In their reflections, this was entwined with the project's open-endedness. In RMA's words:

> It's different because like at my robotics camp that we were doing, everything was already pretty much built in for us. And so we just had to figure out what, how to code it, to make it do what we wanted it to do, which was really easy. But here it's a little more of a challenge, which is better because it's not like the answers are given to you. You have to figure it out… we had to build our thing completely – our base with the circuit playground and all that stuff. And so we got to see, like, I got to see the complete progress of what I did and how well it worked. And so that was really fun… And so to see how we can, like how I *actually* made something that works – and that can coincide with what I'm working on [personally], as far as like *my* projects…

Like RMA, KH described the kit as, at times, fun and familiar, while at other times hard. Considering how she would describe the workshop to friends, she said:

> I guess I was saying that it's hard. I would say it's hard. And you had to be very dedicated and that it's not just your image of working at a computer. You're actually working more hands-on. You have to focus! And if you mess up, you're going to have to restart. You're going to have to hear people out and listen to them. You'd have to listen to people ideas because you can't do it by yourself.

Working through moments of frustration and confusion with materials and activities, a number of learners described a sense of difficulty then accomplishment, through which "what you're doing" when building computational systems became visible.

C. Perceptions of Self and CS

Coming in the camp, neither RMA nor KH considered CS to be an area of expertise nor interest. Both saw themselves as creative and artistic, and created careful and sophisticated sketches to represent their identities, interests, and screen names, *Coding Samurai* and *Creative Coder*, respectively. In project work and a pre-post survey of competency and perceptions of computing, RMA and KH (indeed most of the participants) demonstrated increased understanding of how circuits and computing systems work, and in interviews, described seeing new possibilities in coding and CS.

For both young women, the surprising mix of materials and tasks seemed to 1) bring together existing and emerging identities and 2) shift a view of the computational world as designed and designable. For RMA, computing work in the camp looked markedly different than what she had seen before. The ability to foreground her drawing skills seemed to catalyze a recognition that computer science, which had seemed hard, boring and just about making a lot of money, could be "easy and fun," with "so many different ways to do it." She was able to relate to her sister's interest in coding, as well as to her brother's attempts to fix appliances around the house.

For KH, the workshop shifted a perception of CS as "just sitting at a desk all day," to being about "building and putting together." She talked about loving the paper and cardboard components. In addition to feeling like she was taking things apart, these helped her realize that computational systems were in many things around her:

> What's your, your little – with the little cardboard connectors? I love those. I didn't know what they were gonna be used for and I'd never used them before. So it was so interesting to use them. It was like - I wanted to keep doing it all day…. It made me realize that everything around me is filled with computers. Like every, most of the things I have that I can use, I can use computer with music and art and I didn't know that, like, when you talked about the different artists that was talking about the way that they express their STEM through their art, it was really cool.

Similarly, RMA described a new sense of not only how technologies could be used for her purposes, but how all technologies were designed by someone because they – some real person – wanted to do something:

> I guess it's just – how do I explain – probably like it would be easy to do it because like, if you're passionate about something, you care about something, then it's pretty much a goal. So people use, like, technology to express things that they care about all the time. I mean, I'm sure like with the people that created a phone is probably because they want to talk to people. And so, um, instead of writing letters all the time….[also] probably electric scooters because people, you know, how people like scooters and all that stuff, instead of using all their energy.

Designers in the camp began to realize that computing and CS is something they could do. Though we make no claims about the long-term impact of the short workshop, this dawning understanding of the computational world as designed and designable – stuff that's made by people, and stuff that I can

make – was a positive direction in our eyes.

IV. Findings & Implications

Overall, the young designers expressed and demonstrated an increased interest and belief in their ability to work in CS, as well as a shift toward a view of CS and computational devices as reflective of the purposes and work of real people. Work with the kit and activities provided opportunities for young designers to bring personal narratives – from theater, art, social issues, and more – into CS learning and to leverage prior experiences in both the processes and topics of their projects. Using materials designed to make inputs to a computational system investigable and modifiable, participants valued feeling like they could "actually" create computational artifacts themselves and see the progress they were making.

The study illustrates new forms through which creative computational engagement can be facilitated – in this case, paper cards that engage users with computing concepts, craft materials, open design prompts, and programmable components – and new ways technology designers might navigate tradeoffs between usability, flexibility and conceptual power [16]. Attributes of the kit and workshop that seemed to contribute to shifting perceptions of CS and self in CS included:

- Novel combinations of materials inspired reconsideration of what computing systems can be and allowed learners to use materials in their homes;
- Using cards to juxtapose conceptual and design elements motivated discussion of both computational and aesthetic aspects of projects;
- Creating sensing circuits from a mix of materials demanded that learners engage with problem solving and "figuring out", an important aspect of CS and engineering practice;
- Remote participation recentered *doing* and *being* in CS around participants' resources and communities.

Lastly, considering the workshop experiences in relation to goals of equity-centered computing education, we came to the idea of *seamfulness* as a useful design strategy that captures some of the workshop's successes. *Seamful* designs encourage users to encounter the transitions or transformations between parts of a system. Like *transparency*, the term has been placed in opposition to computational blackboxes [27], [28]. Yet in contrast to a metaphor of "transparency," in which a goal is to make objects and systems visible to – or *for* – a learner, designing for seamfulness evokes a learner able to investigate and modify, for themselves, how a system is stitched together.

Seamfulness speaks to how we saw frustration, surprise and iteration happen in making. A sense of accomplishment and a realization of oneself as a capable CS learner seemed linked to a need to *figure out* something that felt hard and indeterminate [29]. At times, rough seams of the kit also created surprise that fostered a sense of shared space in which youth felt they *belonged*, an important quality of CS learning [30]. Complaints about copper tape and smelly paint became markers of the workshop experience around which participants laughed, commiserated, and shaped narratives of participation.

Seamfulness also frames for us a key challenge of justice-centered education: making visible and/or explicitly addressing social and political systems that structure trajectories in CS. To reveal seams is to expose, instead of smooth over, the difficulty of bringing systems together. Cameron [31] poses seamfulness as engagement with power and unspoken norms, articulating an ethos of bricolage and mixtapes that leans away from mainstream polish and revels in outsider status. She depicts a kind of creation in tune with the narratives and aesthetics we see in computational projects that bring together personal, political and pop culture, foregrounding stories and knowledge-in-the-making that are often stigmatized or stereotyped.

As they worked at the seams – navigating unreliable circuits and trying to transition between art, craft and computational layers – we saw participants recognize that real people had to work hard to create the computational devices they use every day. This step, of recognizing the world as designed and designable, is important to exercising agency [32]. We believe these moments can and should be leveraged to consider, with young people, the social as well as technological systems of computing and power.

V. Limitations and Conclusions

In this analysis, we attempted to capture shifts in how young people saw what computing is and what it is possible to be and do in CS. We recognize many limitations of this study, including the small number of participants and short duration of the workshop. Our analysis of the reflections of young people does not fully warrant claims about what they learned in and from the workshop. Our analysis was conducted without participation of the young designers, by researchers who grew up in different places, with different circumstances, and in different bodies than the people whose experiences we described and interpreted. We also recognize the limitations of this report, importantly its omission of facilitation and relational work. This work was critical to both the storytelling and computational work the young designers did.

In the young designers' embrace of messy creation, their delight at the novelty and difficulty of encountering paper and cardboard, and in the joint creation of an ephemeral computational community, we see the possibilities of seamfulness as strategy for equitable CS education. Seams and seamfulness can encourage learners to take things apart, pay close attention, seek help, and reimagine. When desired outcomes include sustained participation in and transformation of CS, seamfulness reminds us to think about how friction, not just transparency, might direct learners' attention toward both computational concepts and new possibilities.

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