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Putting Making into High School Computer Science Classrooms: Promoting Equity in Teaching and Learning with Electronic Textiles in *Exploring Computer Science*

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ABSTRACT
Recent discussions of making have focused on developing out-of-school makerspaces and activities to provide more equitable and enriching learning opportunities for youth. Yet school classrooms present a unique opportunity to help broaden access, diversify representation, and deepen participation in making. In turning to classrooms, we want to understand the crucial practices that teachers employ in broadening and deepening access to making. In this article, we investigate two high school teachers' approaches in implementing a novel eight-week, electronic textiles unit within the *Exploring Computer Science* curriculum, where students designed wearable electronic textile projects with microcontrollers, sensors, and LEDs. We share teachers' emergent practices in transforming their classrooms into makerspaces, including valuing student expertise and promoting connections in personalized work. We discuss the ways these practices succeeded in broadening access to making while deepening participation in computing and establishing home-school connections.

KEYWORDS
Equity; Teaching Practice; Maker Education; E-Textiles; Computer Science Education

Broadening, deepening, and diversifying participation in making

During the last decade, making has been promoted as a promising approach to inviting broad student participation in rich STEM experiences (Blikstein, 2013, Honey & Kanter, 2013; Peppler, Halverson, & Kafai, 2016). A growing network of makerspaces in afterschool clubs, community centers, museums, libraries, and FabLabs engage youth in developing their interests in the historically exclusive domains of computer science and engineering by building on personal interests, supporting inquiry, and sharing expertise. Yet increasing numbers of critics voice concerns about the limitations in youth access to such makerspaces, issues with limited representations of makers and making, and lack of opportunities for students to deepen their participation in making (Blikstein & Worsley, 2016; Calabrese Barton, Tan, & Greenberg, 2016; Vossoughi, Hooper, & Escudé, 2016). Addressing these equity concerns about participation, representation, and learning is particularly urgent as makerspaces and activities move into K-12 schools.

We see three key issues to equity in making that have led us to computer science classrooms as a way to address some issues of equity, though each of these issues brings up new challenges in return. The first issue regards broadening access to participation and deals with the lack of availability of makerspaces in underserved communities. Efforts to resolve this have begun by creating spaces for making in low-income and underprivileged communities through afterschool clubs, community makerspaces, libraries, and museums (Blikstein & Worsley, 2016; Calabrese Barton et al., 2016; Sheridan et al., 2014;

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Vossoughi et al., 2016). However, one overlooked area of access is that participation in most of these making spaces is largely voluntary: They depend on youth interest to come and persevere in maker activities. This is why many people turn to classrooms as an additional possibility to make these extracurricular educational opportunities accessible (e.g., Blikstein, Kabayadondo, Martin, & Fields, 2017; Collins & Halverson, 2009). While schools can reach many more students over extended time periods, participation in making is inherently interest-driven and this raises a fundamental tension: If we put making into an academic-based classroom (i.e., not a special "maker" class or afterschool program), how do we maintain students' interest-driven engagement at the center of making objects of personal relevance?

A second issue is diversifying representations of making. The public face of the Maker Movement has not been inclusive of our diverse population in the US, as the overwhelming majority of *Make Magazine* covers feature men, white people, and expensive machinery like robots and drones (Brahms & Crowley, 2016; Buechley, 2013); the Silicon Valley culture of "autodidactic" (self-taught) hackers and a money-making market has been privileged (Blikstein & Worsley, 2016; Vossoughi et al., 2016). By contrast, handcrafts reveal making practices that are more inclusive of gendered (Parker, 1984) and indigenous (Medin & Bang, 2014) influences, and can help students strengthen connections to history and cultures, and be linked to content knowledge in school. However, such work has been long considered vocational, non-academic, and low-tech (Rose, 2014), in contrast to maker activities that require programming, engineering skills, and high-tech tools. We wondered if the introduction of handcrafts in academic classes, in schools that serve marginalized populations, would help diversify who makes and the kinds of artifacts that are made. Yet, finding teachers, tools and activities that can bridge these divides between different technologies and connect to curricula in schools presents formidable tensions.

A third issue is deepening participation to increase depth of making and associated learning. The maker education movement is full of "hero" stories featuring individual youth who make very challenging projects that lead them to develop skills in mathematics, science, computing, and other difficult domains (e.g., Hatch, 2014; McGaillard, 2016). Yet in school we need to pay attention not just to the exceptional students but to all students to ensure they have access to challenging learning opportunities (Margolis, Estrella, Goode, Holme, & Nao, 2010). In pursuit of ways to draw more students into making, many educators have developed short, interesting activities that are very limited in scope. Blikstein and Worsley (2016) call this the "keychain effect," referring to a common introduction to 3D printing where students remix a simple design for a keychain by changing the lettering to their name or initials. Making keychains, like many introductory making projects, is quick, simple to teach, and results in personal designs. Students enjoy it but many are often too content with the easy project, not progressing to more challenging endeavors. Further, as has been recognized for decades in the constructionist movement in education (e.g., Kafai, 2006), not all interests are created equal or lead students to similarly challenging learning opportunities (Kurland & Pea, 1985). In classrooms, teachers are tasked to engage all students in more advanced projects and to learn challenging skills and knowledge in the process. Yet again, a tension emerges about how to let projects be personal and different while also attending to curricular learning goals.

These three equity issues—broadening access, diversifying representation (by privileging non-dominant makers, techniques, and artifacts), and deepening participation—formed the impetus for developing a curriculum for making activities that could take place in classrooms in a particular academic discipline, namely computer science (Fields, Lui, & Kafai, 2017). Computer science, like the Maker Movement, has a longstanding history of inaccessibility to non-white, non-male students from working-class communities (Margolis & Goode, 2016). To address the issue of broadening access, our maker curriculum was situated within *Exploring Computer Science* (ECS), an equity-focused and inquiry-based introductory computer science course taught in public high school classrooms all over the country (Goode, Chapman, & Margolis, 2012). To diversity the artifacts made, we selected electronic textiles (e-textiles), which utilize programmable circuits hand-sewn onto soft objects like clothing and stuffed animals, with conductive thread, LEDs, digital sensors, and sewable microcontrollers (Buechley, Peppler, Eisenberg, & Kafai, 2013). To deepen student participation in making, our curriculum consisted of a series of increasingly difficult e-textile projects that introduced challenging concepts in coding, circuitry, and crafting (see Fields et al., 2016). While prior e-textiles activities in afterschool, workshop, and even some classroom settings were almost all facilitated by researchers (e.g., Buchholz, Shively, Peppler, & Wohlwend, 2014; Kafai, Fields, & Searle, 2014; Litts, Kafai, Lui, Walker, & Widman, 2017), classroom teachers led our program implementation with their own students, with researchers present in the room only as observers.

This study seeks to illustrate how an equity-focused making curriculum in ethnically diverse computing classrooms can support the types of curricular and pedagogical experiences that are aligned with culturally responsive computing. Drawing from Scott, Sheridan, and Clark (2015), five tenets shape a culturally responsive computing environment:

1) all students are capable of digital innovation
2) the learning context supports transformational use of technology
3) learning about one's self along various intersecting sociocultural lines allows for technical innovation
4) technology should be a vehicle in which students reflect and demonstrate understanding of their intersectional identities
5) barometers for technological success should consider who creates, for whom, and to what ends rather than who endures socially and culturally irrelevant curriculum (pp. 420–421).

We wondered how an instructional design focused on involving all students in making, with extensive opportunities for student choice and personalization of design, could support the type of identity-building and technological innovation that are sparked in culturally responsive computing classrooms. Further, we sought to focus on teacher practices that support this type of engagement in making computational artifacts.

In this article, we address the following research question: What are the emerging teaching practices promoting equity? We analyzed video recordings and field notes of two teachers who implemented the new e-textiles unit of the ECS curriculum, paying particular attention to how they supported interest-driven, student-centered making of e-textiles within the constraints of high school classrooms.

Background

Equity and community practices in the ECS curriculum

Exploring Computer Science was selected as the setting for our e-textiles unit because the course was specifically developed to challenge the persisting underrepresentation of women and people of color in computing, as well as the systemic and political barriers that continue to exist in computer science education (Goode, Margolis, & Chapman, 2014). Compared to other computer science courses, ECS students represent their school communities more accurately in characteristics like race, ethnicity, gender, primary language spoken at home, and in their participation in the Free and Reduced Meal Program, a measure of their family's poverty status. In ECS, students learn through inquiry and project-based activities, and develop a repertoire of computational practices (Goode et al., 2012), which connect computing with the students' everyday experiences (Scott, Sheridan, & Clarke, 2015). Thus, designing an e-textiles curricular unit for ECS gave us the opportunity to work with a diverse population of students previously underrepresented in the Maker Movement.

The new e-textiles unit was designed to be taught by ECS teachers in the classroom. Therefore, the activities had to support the equity-minded and community-building practices already established by the teacher. Examples of ECS teachers' culture-setting practices include utilizing an inquiry-based approach, which involves prompting students to think and explore with open-ended questions, focusing on process rather than the identification of a "right" answer (Margolis, Goode, & Ryoo, 2015). ECS teachers develop these teaching practices by participating in a two-year professional development program, ongoing teacher mentoring, and computer science teacher communities of practice (Margolis & Goode, 2016). While we anticipated that the ECS course would be a great fit for our e-textiles pilot study, we did not know yet how these core values of ECS, such as learning through inquiry and equity-minded teaching practices for diverse learners, would apply when transforming their computer science classrooms into makerspaces.

Design of the maker studio model for electronic textiles

Our e-textiles unit introduced new concepts to extend the existing ECS curriculum and approach. First, our classroom maker activities were designed with diverse learners in mind. We wanted the projects to take computers "off the screen" and onto touchable, malleable, and interactive toys, clothes, and other objects students could design, yielding personalizable, soft artifacts that are typically not found in a computer science course and could be taken home. In designing these activities for ECS students, we were guided by *constructionist theory*, the idea that learning happens through the creation of artifacts that can be shared with others (Papert, 1980). Constructionist activities in the computer science classroom align well with the *studio design model*, a pedagogical philosophy and approach from arts and architecture education, with the fundamental belief that creativity is a deliberate process that can be taught and learned (Sawyer, 2017). Research in other settings has shown that creating e-textiles also can disrupt students' previously-held stereotypes of computing and making (e.g., Buchholz et al., 2014; Kafai et al., 2014).

However, we anticipated that classroom teachers would struggle to encourage each student in personalized projects and to motivate and guide students' creativity (Sawyer, 2017). In many makerspaces and e-textiles interventions, multiple adults are present to help students create unique projects (e.g., Litts et al., 2017; Sheridan et al., 2014), but in a school classroom, it would be nearly impossible to customize learning experiences for each student just by having adults give them special mentorship (an extremely large ECS class had 46 freshmen enrolled). We knew that teachers would need to establish an inclusive environment that values students' *funds of knowledge* or varied expertise (González, Moll, & Amanti, 2006), and rely on *peer pedagogy*, students teaching one another (Ching & Kafai, 2008). Since most of the work on peer pedagogy has focused on students working within small collaborative groups with clear expert and novice roles, we did not know exactly how the teachers might implement peer pedagogy in the e-textiles unit which only included one project with a collaborative group (pair) and did not have designated experts and novices among students as they were all new to e-textiles at the beginning of the unit.

The ECS equity-oriented approach, constructionist theory, and e-textiles projects that bridge handcrafts and computing laid the groundwork for tackling the three issues of broadening, diversifying, and deepening making in discipline-based classrooms. However, teaching the unit was the key factor needed to put ideas into action in actual classrooms. In particular, we were concerned with the challenges teachers faced in introducing making e-textiles in ways that valued student interests and personalization while supporting equitable depth of learning, especially in the face of limitations of time (school-based class periods) and staffing (one teacher rather than the several mentors more common in makerspaces). Further, the two teachers who implemented the unit had never done "making" that combined digital and physical elements and certainly had never done e-textiles before training. In this paper we ask the broad question of how does one teach making e-textiles in computer science classrooms in ways that support equity? More specifically, what practices did teachers develop that supported students' e-textiles making that was personal, interest-driven, and rigorous?

Context of implementation

Drawing on two related areas of expertise, e-textiles and ECS experts co-developed the curricular unit and designed it to be taught as one of the final units of the ECS course, replacing either the Data or Robotics units. The resulting curriculum contains big ideas and recommended lesson plans, with much room for teachers to interpret and bring in their own styles. In the design of the six e-textiles projects (see Table 1), we prioritized helping students learn challenging concepts in computing, electronics, and crafting while also supporting personal expression and design (Kafai et al., 2014). For instance, the final project incorporates a handmade human sensor created from two aluminum foil conductive patches that when squeezed generate a range of data (see lower right, Figure 1). In this project, students used these data to program different lighting effects so that the lights changed based on how hard a user squeezed their project. Most of the circuitry and crafting skills students used were completely new to them. The programming skills built on concepts introduced in the Scratch unit such as sequences, loops,

Table 1. Sequence of projects in the e-textiles unit.

Project	Description	Content
#1 Paper Circuit (~1–2 hrs)	Single circuit project design: Create a simple paper circuit greeting card that includes one LED. Introduce the concept of aesthetic design and personalization.	• Simple circuit • Polarity • Materials: LEDs, copper tape (wire), paper
#2 Stitch Card (~2–3 hrs)	First sewing project: Create a night-sky scene with one or two LEDs. Learn basic conductive sewing.	• Simple circuit • Conductive sewing • Materials: Conductive thread, paper
#3 Wristband (~4–5 hrs)	Simple wearable project: Create a wristband with three LEDs in parallel and a switch that turns on the project when the ends of the wristband are snapped together.	• Parallel circuit, switch • Reading circuit diagrams • Three-dimensional project • Materials: Conductive thread, LEDs, fabric
#4 LilyTiny Project (~4–5 hrs)	First custom design project: Use the pre-programmed LilyTiny to create a hand-sewn project with 3–4 LEDs that each operate separately.	• Computational circuit • Pre-programmed microcontroller • Custom circuit design, drawing circuit diagrams • Materials: Conductive thread, LEDs, fabric
#5 Collaborative Banner Project (~10 hrs)	Collaborative project: As a class create a banner, with each letter made by two students together. Each letter must have five independently programmable LEDs and two switches, allowing for four blinking light patterns.	• Programming: Sequences, conditionals, embedded conditionals *or* Boolean statements • Collaborative work and division of labor • Materials: Conductive thread, LEDs, fabric
#6 Human Sensor Project (~10 hrs)	Capstone project: Create a project with two aluminum foil patches that act as a sensor when both are touched by a person. Program four+ lighting patterns based on different sensor readings.	• Sensor design (handcrafted) • Programming: operators, sensor range, Boolean statements • Materials: Conductive aluminum foil, human body, LEDs, fabric

conditionals, and variables, but required students to apply these in a new context: a text-based language (Arduino). They also had to learn new programming skills, such as nested conditionals, data input from sensors, and functions. Learning these challenging skills in the context of making handcrafted, personalized objects helped support our goal of diversifying the objects of making in computing classes.

Participants

In Spring 2016 two teachers from a large school district in California piloted the e-textile unit in their ECS classes. They had more than seven years of teaching experience each, had completed the two-year equity-focused ECS professional development, taught ECS for several years, and were recognized by ECS

Figure 1. Gallery of sample student projects in the e-textiles unit: (upper row) paper circuit, stitchcard, wristband, lilytiny; (lower row) banner project selections, human sensor project.

staff as teacher-leaders who understood the ECS values. The teachers engaged in three days of professional development (once a month for three months), where they became familiar with the curriculum by designing and creating the six e-textiles projects students would make.

Ben taught at Valencia Glen Charter High School in the northwestern suburbs of the metropolitan city. VGCHS enrolls about 4,600 racially-diverse students (4% African American, 18% Asian, 10% Filipino, 40% Hispanic or Latino, 25% white, 1% two or more races, and 2% race not reported), and 54% of Valencia Glen's students are from socioeconomically disadvantaged families, 3% are English learners, and 60% are academically on-track or deemed college/career ready. ECS was a required elective class for ninth graders in the STEM track at the school. The pilot class included 13 girls and 22 boys (32 of 35 students gave consent/assent for research).

Angela taught at a small, alternative magnet school in the south of the metropolitan city. Douglass & Williams Magnet High School for Medicine and Science enrolls about 1,600 students, with 43% African American, 56% Hispanic or Latino, and 1% white. Eighty-nine percent of DWMHs' students are from socioeconomically disadvantaged families, 3% are English learners, and 53% are academically on-track or deemed college/career ready. Although the school requires all students to apply for admission, not everyone participates in DWMHs' desirable magnet programs. Angela told us that ECS was considered a math elective taken by students who lacked the requisite course credits for the school's hospital internship program. Angela's pilot students were juniors and seniors, 11 girls and 13 boys (21 of 24 students gave consent/assent for research).

Research team

The 12-person research team harkened from four different universities, with four lead faculty members. Two faculty (Kafai and Fields) were pioneers in maker education and have worked with e-textiles for 8–10 years, authoring many publications on the topic. Two other faculty (Goode and Margolis) and one staff member were co-founders of ECS. All four faculty members and the staff member identify as female, with four of white American origin and one of Middle Eastern/European origin. The team also employed two female post-doctoral researchers, one white and the other of Asian descent. The rest of the team identified as people of color, including four PhD students and a research-school district liaison (Landa). Two of the non-PIs were male. Six team members were former high school teachers. Fields led the curriculum development and the professional development workshops, with major contributions from Landa and a PhD student (Nakajima).

Methods

The study is part of a larger design-based implementation research study (Penuel, Fishman, Cheng, & Sabelli, 2011) where the goal is to develop and revise an e-textiles unit over the course of three years, attending to problems of practice in the classroom to develop better theories of pedagogy related to making and computing and support classrooms in sustainable changes as they bring making to computer science. This study attends to the first year of the project, where two teachers implemented the curriculum and two researchers (Fields and Nakajima) gathered data focused on teacher practice in the classroom, visiting each class equally, four days a week (about eight weeks, with interruptions from holidays, testing, and other school obligations). The researchers positioned themselves as objective and passive observers by not helping to teach the classes and only addressing the students when collecting data. Despite inherent biases toward evidencing a successful implementation, we also wanted to capture areas of improvement to significantly revise the curriculum for subsequent pilot classes. With these aims, we documented teaching with detailed field notes (consulting with each other repeatedly to match focus and level of detail in the notes), in-class video and audio recordings, and pictures/videos of student work, supplemented by an interview with each teacher before, during, and after the unit, and daily recorded reflections by the teachers after each class[1]. Brief focus group interviews at the end of the unit invited students to describe the highlights of the e-textiles unit, how it fit within their year of ECS, and what changes students would make to the unit.

After the school year and the pilot project had ended, the research team analyzed the field notes using constant comparative analysis (see Charmaz, 2011) toward two goals. First, one group looked at computational thinking practices exhibited during the e-textiles unit, comparing this with the larger corpus of computational thinking practices identified in the AP Computer Science Principles curriculum (College Board, 2016). The results from this analysis alone are reported in Fields et al., 2017 and highlight the ways that teachers supported iteration, revision, problem solving, collaboration, and creativity. Second, other members of the research team separately coded the observational notes for teaching practices that supported equity, drawing on literature from prior ECS analyses by Margolis et al., 2015 and Darling-Hammond's foundations of equitable teaching (2008). Throughout this process both teams met weekly as a research team to compare notes and share insights.

In a comparative stage of analysis, researchers looked across these two coding schemes for areas of overlap, identifying two sets of practices in particular that stood out as supporting students' personal and interest-driven making: supporting students as experts and facilitating students' personal connections to content in the classroom. Researchers then re-coded the data to find all of the teaching practices in these two areas. After, the team compared findings from observational data with the interviews from teachers and students to see whether these practices came up from participants' perspectives and to understand these two areas in greater depth. The entire manuscript (with emphases on the findings and analyses), was also read and reviewed multiple times by critical scholars with social justice orientations.

Findings

Both teachers reported that the e-textile unit engaged nearly all students in their classes and that the design of project activities was malleable enough to work with both of their pedagogical approaches. In the following sections, we share two teacher practices that emerged: legitimizing student expertise and supporting personal connections in e-textiles projects (see Table 2 for a summary). These practices helped broaden access, diversify representation, and deepen learning in making with electronic textiles.

Table 2. Summary of findings.

Finding	Practices	Examples
Legitimize Student Expertise	Use student work in whole class instruction	• Use student artifacts from Project 1 to teach concepts for Project 3
	Publicly share student solutions to problems	• Pose open-ended problem and have students share multiple solutions
	Encourage peer pedagogy (formal)	• Students evaluate one another's work • Experienced students teach other students (using distributed expertise) • Assign group projects
	Encourage peer pedagogy (informal)	• Allow student work to be visible. (Example, group student desks to face one another creating common table space)
Support Personalization & Student Connections	Pace lessons to prioritize time for student creativity	• Give ample time in the preliminary design phase and at the end of each project for adding personal touches
	Students bring artifacts from home to class	• Projects can use class supplies or augment already existing artifacts (e.g., clothing, stuffed animals, backpacks)
	Valuing students' funds of knowledge	• Students can use making skills & expertise originally learned outside of school (e.g., stitching techniques learned from watching mom sew)
	Encourage mobility of projects (to/from home)	• Encourage students to solicit feedback & help from family members & others • Trust students to take responsibility for their artifacts-in-progress, materials, tools
	Support friendships between students	• Encourage student talk while crafting, even when conversations are off-topic • Group desks/tables to promote conversation

Teaching practices for legitimizing student expertise in the classroom community

One set of teaching practices that promoted equity involved valuing students' expertise and making it visible to other students. By doing this, teachers foregrounded student knowledge, validated students' efforts (including their mistakes and fixes), and supported students in going deeper into their projects. They did this in several practical ways.

First, the teachers featured students' projects during key, whole-class teaching moments. For instance, Angela used two students' paper circuit cards (Project #1) as a way to introduce how to create parallel circuits (160406 FN[2]. She showed photographs of their cards (laid out with visible copper tape showing the circuitry) alongside her own diagrams of how multiple lights could be connected in parallel. Teachers also made student expertise visible in asking open-ended questions and encouraging students to share their knowledge. In another activity to create computational circuits (circuits that light up in connection with a computer rather than directly linked to a battery), Ben had students draw diagrams individually and then invited students to come up to the board to share what they had drawn (160418 FN). Not only did this encourage a type of discovery-based learning, where students had to make informed guesses about how to create a computational circuit diagram based on an inquiry activity, but it allowed for the display and discussion of multiple solutions to a circuitry problem. Foregrounding student knowledge in front of the classroom framed students as sources of knowledge and validated the new expertise they were developing in the areas of circuitry and coding.

The teachers further legitimized student expertise by supporting peer pedagogy (Ching & Kafai, 2008) with students helping and teaching other students. This happened in multiple ways both directly and more indirectly. For instance, often a teacher explicitly invited a student to help another student. Angela did this by requiring that student pairs approve each other's circuit diagrams before they moved on to crafting (180405 FN). If students still turned to her as the teacher for approval, she redirected them to their neighbor and asked if their neighbor approved of their diagram. In addition, the teachers occasionally took advantage of the fact that some students progressed more quickly through their projects and encouraged others to approach those students for specific assistance. For instance, in Angela's class, Tonio was one of the first to iron on his aluminum foil patches for his human sensor project. Angela gave him a personal tutorial on the ironing technique and a few days later as she began class she referred students directly to him for help with ironing (160602 FN). During and after that class several students approached Tonio for assistance as he taught them how to use the miniature irons to get the aluminum foil with the heat-sensitive adhesive to adhere to their projects (see Figure 2). This strategy of having students help each other again framed the students as experts alongside the teacher and freed teachers' time to help with the more difficult problems that arose.

Other forms of peer pedagogy were more indirect results of the teachers' spatial and classroom management designs. For instance, the physical structure of the classes with clusters of 4–6 students sitting around common tables with shared supplies alongside classroom management that allowed for light banter amongst students supported a near ubiquitous peer pedagogy between students. Because of proximity, problems were often visible (in the form of messy touching threads) or overheard (when students expressed frustration with something). This made peer support of debugging quite common, as Parushi (Ben's class) described:

Figure 2. Tonio tutors Moisés in how to iron aluminum foil patches onto his project.

> I'd sewn the light incorrectly when [my partner, Emma] was doing the coding. The next day, she came back and was like: Oh, it's wrong! And we had to re-sew it three times [laugh]. I probably would've taken out the whole stitching if I was doing it alone, but she … cut it off in a different way … tied [it], and it worked much better than I probably would've done. (160525 interview, Parushi)

In this example, Emma found a mistake that Parushi had created while sewing and also showed Parushi a clever way to fix the problem without having to remove all the stitching. Many students shared similar moments like this, crediting their peers with help in stitching techniques, coding, debugging, and simple encouragement. As Diego (Angela's class) expressed about his nearby peers, "Sometimes … I'll be lost, and my partner and the person across from me [would] help me with this. They show me, and I got to see how to learn" (160602 Diego, interview). By their own reports, peer pedagogy (seeing and showing others "how to learn") helped students go deeper in their understanding of ideas behind e-textiles and how to debug them. It also served to diversify who was a knowledge expert in this making and programming: students who helped others or shared ideas in front of the class participated in roles of teaching.

Teaching practices for supporting personalization and connections in student projects

Another set of teaching practices emerged around creating an environment that facilitated the personalization of objects that students made and the relationships they built in the class. The teachers ensured that project designs allowed ample room for creativity within the selected constraints (i.e., a certain number of independently programmed LEDs), enabling students to display personal interests in their projects. Students' projects displayed abundant personal expression in what they looked like and who they were intended for: Paper circuits became birthday cards for friends, wristbands displayed initials and popular media motifs, and LilyTiny projects became monsters, hearts, and cartoon characters. In the banner project this became a blend of classroom and personal expression: The class (with the directing help of the teacher) chose a phrase for the banner, and within that theme pairs of students found ways to customize the individual letters they contributed.

Consider the experiences of Clarence and Everett (Ben's class) who were assigned the letter "S" in the chosen class banner phrase: "VGCHS COMP SCI 2016!!!" (which stands for Valencia Glen Charter High School Computer Science 2016!!!). Because there were two "S" groups, Clarence and Everett (Ben's class) intentionally worked to make theirs different, choosing to make the S like a snake in a southwest desert theme (160516 FN, see Figure 3). They expressed their pride in their shared student interview, describing their unique layered design, how they covered the conductive thread "wiring," and why they hid the LilyPad (i.e., the microcontroller) within the layers of felt. This freedom to make creative choices and the work they put into their project gave them a lot of pride in what they accomplished and in its uniqueness.

Figure 3. Clarence and Everett's southwestern style "S."

The teachers directly supported this personalization by foregrounding personal creativity in students' projects, most particularly by prioritizing time at the beginning of the project for students to draw a picture of what they wanted to create, even if that picture changed considerably as students added and revised circuitry diagrams or began the actual crafting. For instance, even on the very simple paper circuit project, Angela (160329 FN) told students to first design how they wanted the card to look and then to add circuitry. As we have found with other e-textile projects (and conveyed to the teachers during professional development training), when the aesthetics or design of the project is put first, students are more invested in their projects and even learn more through the design changes they make in order to achieve the desired effects (Kafai et al., 2014). In contrast, foregrounding accurate circuitry seems to have the opposite effect as students tend to stay with what is taught rather than adding in personal elements. The teachers put these concepts into action by making time at the beginning of class as well as providing ample time at the end for customizing projects.

Beyond focusing on project design and foregrounding aesthetic drawings, three other teaching practices stood out in regard to facilitating personal and cultural connections in the classroom. First, teachers allowed and sometimes outright encouraged many students to bring in objects from home for their e-textiles projects. This was especially true of the final project, the human sensor project, as students brought in sweatshirts, purses, stuffed animals, and even a dog halter to augment with sensors and actuators. Adding electronics to an existing personal artifact provided a means to bring something from home to school in a way that was academically legitimate. Second, students made connections with skills they learned from home or by involving family members in their projects at home. For instance, Nishma (Ben's class) used a blanket stitch that she had learned at home for attractive edging on her final project (160525 FN). Diego (Angela's class) used a technique of licking the conductive thread to smooth and stiffen the edges before threading it—something he had observed his mother do at home. Bringing objects and skills from home supported students' agency and promoted connections across spaces in their lives all while helping to diversify what counted as valuable objects and knowledge by expanding that beyond the classroom to home expertise (or funds of knowledge, e.g., González et al., 2006).

Many students also took their work home to finish it, and this provided an opportunity to get feedback from family members and peers. Ben modeled this to his class when he explained that he had his wife test the sensors on his human sensor project and found that she got a much smaller range than he did (160531 FN). While all students were encouraged to have others test the range of the patches on each other so that they had an idea of how to customize it for broader usability, one of Ben's students, Kadir, took this a step further and tested his human sensor patches on his dad while his dad was sleeping. In fact, Kadir took many of his projects home and suggested that students be encouraged to take work home more:

> I wouldn't change anything except let us take it home, to work on it at home sometimes. 'Cuz I took multiple projects home, tried to get them done. My family, I got their opinion, I changed things here and there. (160525, interview)

Most students remembered Kadir's greeting card because there was a tremendous difference between how it looked at the end of one day and at the beginning of the next day after he had taken it home. Again, supporting connections through the movement of objects and skills between school and home is a powerful means of valuing students' interests, families, and home cultures and diversifying representation in who counts as an expert in making.

The ability to take projects home should not be taken for granted; it demonstrated trust in the students to be responsible for materials. At the beginning of the e-textile unit, the teachers expressed some concern about allowing students to take projects home. Relatively new themselves to the materials, they worried about whether students would remember to bring projects back and were acutely aware of the material costs involved, especially the $20 microcontroller that was used in both the banner and human sensor projects. Though the grant supplied the materials, there were few replacements available, and it cost about $45/student. We witnessed the two teachers shift in their views as they adjusted to incorporating material making in their classrooms: teaching students about the value of the materials, developing class-wide practices for organizing, distributing, and cleaning up materials each class period, and trusting students to return with their projects intact and on time. Computer science teachers rarely have to deal with such a vast number of materials (needles, thread, microcontrollers, pounds of felt, hundreds of LEDs, etc.) in their classrooms, and this is one area where both teachers had to adjust. The new practices they developed equipped students to treat materials with respect and to be responsible for them in and out of class, facilitating the powerful connections that students made as they took objects and skills to and from school.

One other aspect of the two classes stood out in regard to personalization, connections, and equity: facilitating peer friendships. During the e-textiles unit, we observed that friendly talk happened quite easily during crafting and coding, especially in the relatively unstructured hours when students were investing time in completing their project. This was in addition (but related) to the peer pedagogy we observed when peers helped on specific project-related tasks. In general, while working on their projects, students talked about everything under the sun. Sometimes this became explicitly supportive as happened with Harold (Angela's class) when he was concerned about his performance on a test. His peers provided camaraderie as they discussed strategies for passing classes while they crafted (160603 FN). In talking about highlights of the e-textiles unit, some students explicitly credited the e-textiles unit with helping them make more friends. Others credited peers for helping them to refocus their attention, learn, and stay engaged. In this way asking peers for help laid the foundation for other forms of talk that began to develop friendships and even to help in times of need, as with Harold. How were peer friendships of this sort supported by the teachers? While it is difficult to pin down a single thing that teachers said or did that supported peer friendships, the physical design of the classroom space in tables, the type of classroom management that teachers supported (allowing movement and banter during work time), and the validation of student expertise (discussed in the prior section) all contributed to allow peer friendships to grow and made the entire class more personal feeling to students.

Discussion

Our article takes a first stab at articulating a "pedagogy of making" (Ryoo, Kali, & Bevan, 2016) that illustrates how teachers can integrate equitable maker activities into computer science high school classrooms. In the introduction we outlined three equity motivations for this work: broadening access, diversifying representation (of makers and objects of making), and deepening participation so that more youth could engage with the rich learning and expressive opportunities promoted in maker activities (e.g., Blikstein & Worsley, 2016).

The pilot implementation was successful in making headway regarding our three motivations. First, the implementation of the e-textiles ECS unit illustrated how a large number of students can participate in maker activities in classrooms with proportionately higher student-to-adult ratios than present in many out-of-school makerspaces and workshops. Both teachers reported that nearly all students were engaged at these two different schools. Furthermore, the implementation did well in diversifying the makers (a wide range of students from different ethnicities, genders, and prior achievement levels) as well as the objects of making. The latter was particularly bolstered in the ways that teachers promoted connections to students' personal interests, funds of knowledge, and even use of their own personal artifacts (e.g., stuffed animals and clothing) within the constraints of the project guidelines. Finally, students attained some level of rigorous learning of programming, circuitry design, and problem solving by completing (or mostly completing) projects. The teachers strengthened this by legitimizing student expertise and allowing students to take on roles of experts in teaching others. Students debugging each other's projects further demonstrates clear evidence of deepening participation, both because debugging is a core area of computational thinking (College Board, 2016) and also because debugging another person's project shows that expertise can be applied beyond one's own project. We believe that considering all three of these issues of equity together in the design and implementation of the curriculum provides a fuller picture of what equity can look like in bringing making into classroom practice.

Our focus in this article was on understanding how the *teachers* took the design of the curriculum and implemented it in their own classrooms in ways that supported equity. While the ECS e-textiles curriculum and professional development training provided a sequence of carefully designed projects as well as pedagogical strategies intended to support students' engagement and learning (i.e., journal questions, discussion prompts, collaborative structures), the teachers were left with the challenging task of putting all of this into practice. Drawing from observations in two classrooms, we identified several key practices teachers developed, focusing on practices related to legitimizing student expertise and supporting personalization and connections. While personalization and connection are considered in the framework of culturally responsive computing environments (i.e., who is making and for whom (Scott et al., 2015), legitimizing student expertise is not generally considered in that framework, though the authors briefly consider peer mentoring as a type of transformational use of technology. Yet framing students as contributing expert knowledge puts students in the lead as technological innovators in classrooms. It allows for more ideas to be shared and, quite practically, helps distribute the teaching load beyond an individual teacher to other students. This results in changing traditional roles in classrooms, expanding who can be a source of knowledge. Notably, our insights come from teacher-generated practices with making and computing, emerging from public school classrooms with all of the time, material, spatial, and other constraints typically present in such circumstances. As more studies take place where teachers implement making in classrooms, more insights can be added to the framework of culturally responsive computing environments.

In particular, we highlight the practices that supported peer pedagogy and peer friendships. Most literature on peer pedagogy relates only to the educational support given by students within small groups for the duration of a project (Ching & Kafai, 2008; Litts et al., 2017). The peer pedagogy described here expands on this as it took place largely outside of small groups without established roles of expert or novice. The teachers supported this by putting students in positions of correcting or approving each others' work and occasionally naming students with developing expertise. They also supported peer pedagogy through less formal means. The physical and spatial design of the learning environment (clustering desks together, sharing physical materials, and having peers' projects easily visible on shared tabletops) combined with the teachers' allowance of casual talk between students promoted peers' casually assisting each other in problem solving with the added benefit of developing friendships through the process. This points to an expanding view of peer pedagogy and how to support it, not just through formal roles or small group collaboration but more as an intrinsic and ubiquitous practice in the classroom, something more akin to that seen in afterschool clubs and virtual spaces than in formal school spaces (e.g., Fields & Kafai, 2009; Sheridan, Clark, & Williams, 2013). Facilitating peer pedagogy and legitimizing students' knowledge also provides a means for a single teacher to create a supportive infrastructure for an entire classroom. The curriculum likely would not have been nearly as successful if students had not taken up roles in teaching and supporting each other. More work needs to be done in developing and supporting richer models of peer pedagogy.

We want to be careful to note that not all of the positive practices we identified happened in every class period. Teachers modeled student projects when opportunities (i.e., mistakes or a particular key concept) presented themselves. Top-down instruction was, by necessity, mixed with other more cooperative means of teaching, and peers did not always get along in helpful ways. Further, much of this was done in the moment, with the intuition of an experienced teacher adapting to a new curriculum and new topic (i.e., e-textiles and making). An additional challenge is that e-textiles requires hybrid knowledge of several different domains (Kafai et al., 2014). This can pose challenges to teachers who might feel more at home in one area (i.e., crafting) than another area (i.e., computing) or to those who are insecure in situations where students may contribute knowledge. Legitimizing student expertise in these situations takes courage. Both Ben and Angela approached this new area with some proclivity to acknowledging student expertise because of their ECS professional development training and expressed as much to us in their interviews. Yet they also had personal insecurities: Ben had never sewn before, and Angela was scared to program in Arduino. However, they overcame these issues when they faced the students and developed ways to further incorporate emergent student expertise into their teaching.

In the coming years we plan to recruit and train many more teachers to implement the e-textiles ECS curricular unit. We hope that by identifying the practices that Ben and Angela developed, we can help other teachers, who are new to introducing making in computer science classrooms, consciously use these practices in order to make those spaces more equitable and supportive to students. In doing this, we hope to add to the research on teaching practices that support equity, particularly in applying making in classroom work. Much more work is needed to support and document making in the classroom, including in other disciplines (such as science or literature), with other teachers, and in different situations. We hope that this will lead to many rich models of making in classrooms, adding to the emerging pedagogy of making that is developing across many contexts.

This article begins to map out some rich and equitable teaching practices in computing and making that move students from initial engagement into more complex projects that can deepen their learning experiences. Shifting making from outside-of-school spaces into school classrooms has the potential to make making more accessible to a broad range of students who, with their teachers, can help the movement work toward its potential for democratization (Blikstein, 2013). This kind of work addresses a piece of the puzzle that has been missing in connecting informal and formal implementations of making activities. It signals a future where learning and teaching in schools can shift to embrace the richness of learning that too often is limited to interactions within informal spaces that are supported by skillful teaching and learners who are engaged through their investment in creating personally meaningful artifacts. In the process new practices of making, learning, and teaching will emerge, calling for research and documentation to ensure that these practices can be named, refined, and shared. In doing so we can help unpack what equitable making in the classroom can look like and promote the kind of making that can truly reach toward the potential of democratized invention.

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Notes

1. This analysis focuses on field notes, which capture the widest perspectives of the class, and student interviews. Other data (e.g., teacher interviews) were used to supplement the analysis but were analyzed separately and are not directly quoted in this paper.
2. We reference data by listing the date (year, month, date: 160406 is April 6, 2016) and type of data: field notes (FN) and interviews.

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