Teaching Practices for Making E-Textiles in High School Computing Classrooms

Full Paper†

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ABSTRACT

[1] Recent discussions have focused on rich STEM learning opportunities and various equity challenges in setting up and researching out-of-school makerspaces and activities. In turning to school classrooms, we want to understand the critical practices that teachers employ in broadening and deepening access to making. In this paper, we investigate two high school teachers' approaches in implementing the *Exploring Computer Science* curriculum using a novel 8-week, electronic textiles unit where students designed wearable textile projects with a microcontroller, sensors and LED lights. Drawing on observations and interviews with teachers and students, we share emergent practices that teachers used in transforming their classrooms into a makerspace, including modeling in-progress artifacts, valuing expertise from students, and promoting connections in personalized work. We discuss in which ways these teaching practices succeeded in broadening access to making while deepening participation in computing and establishing home-school connections.

FabLearn '17, October 21–22, 2017, Stanford, CA, USA

ACM 978-1-4503-6349-5/17/10…$15.00

https://doi.org/10.1145/3141798.3141804

CCS CONCEPTS

• **Social and professional topics → Computer science education;** Computational thinking; *K-12 Education*

KEYWORDS

Equity, making, teaching practice, computer science education, e-textiles

ACM Reference format:
Deborah A. Fields, Yasmin B. Kafai, Tomoko Nakajima, and Joanna Goode. 2017. Teaching practices for making e-textiles in high school computing classrooms. In *Proceedings of FabLearn17, October 21-22, 2017* . 8 pages.

1 INTRODUCTION

During the last decade, the Maker Movement has been promoted as a promising approach to provide access and participation to rich STEM experiences [e.g., 19, 24, 27, 28]. A growing network of makerspaces in after-school clubs, community centers, museums, libraries, and FabLabs has been created to engage youth in developing new interests in historically exclusive domains of computer science and engineering by building on personal interests, supporting inquiry, and sharing expertise. Yet increasingly there have been critiques from within the maker education community about how accessible and how equitable maker activities are [e.g., 5, 9, 34]. One overlooked area is that participation in most of these maker spaces is largely voluntary: they depend on interest to draw in youth and persevere in maker activities. Yet this limits access to those who have the opportunity and take the initiative to search out afterschool makerspaces. This is one of the reasons why many people are beginning to think about classrooms as possible maker spaces that provide access and equity to maker activities [3, 12].

Putting making into classrooms has the potential to reach more students in addition to help students link their making experiences to academic knowledge. Indeed, many teachers interested in making have started to produce and write-up detailed activities that they have developed for their classrooms [e.g., 4]. Yet the research on making is surprisingly sparse on detailing what *teachers* do, and teachers themselves may not be aware of all of the practices that they employ in order to support students in making. While there is a substantial research on good teaching practices in areas such as science, mathematics, and literacy education, observations of teaching practices that relate to computer science education and connect to interdisciplinary maker activities are largely absent from the research literature [1, 25].

In this paper we focus on teaching making in the specific context of computer science classrooms. We selected a particular maker activity, namely electronic textiles (e-textiles) [7], that brings computing and circuits into the realm of handcrafts. E-textiles use conductive thread alongside LEDs, digital sensors, and sewable microcontrollers to create hand-sewn, programmable circuits on soft objects such as jackets or stuffed animals [8]. While e-textiles projects have been used in a number of settings, including after-school, workshop, and even some classroom settings, these have been almost exclusively led by researchers rather than teachers [e.g., 6, 20]. Our study was located in two urban public school classrooms diverse in terms of ethnicity, gender, and class-based measures (see Participants section) To promote academic depth and meet the needs of content knowledge in the classrooms, we created a curriculum with a series of six increasingly difficult projects that included challenging concepts of computing, circuitry, and crafting [14]. Our analysis focused on better understanding how the two teachers integrated making into their computing classrooms through an 8-week unit on electronic textiles, paying particular attention to how they supported interest-driven, student-centered making of e-textiles within the constraints (e.g., staffing, space, time) of high school classrooms. In the discussion, we address the ways in which such teaching practices can tackle equity concerns of broadening access and deepening participation in making.

2 BACKGROUND

We situate our implementation of making with e-textiles within an equity-oriented curriculum for introducing computing in high schools called *Exploring Computer Science* (ECS) [17]. Recognizing the structural and political challenges in computing such as the persistent absence of women and minorities, ECS has successfully addressed these issues through socially-grounded curriculum design and teacher professional development by familiarizing students with a broad scope of computing [16] and connect computing curriculum with students' everyday experiences [30]. Over ten thousands of minority students and thousands of teachers in large urban school districts have successfully participated in ECS [17].

Our introduction of the e-textile maker activity provides a welcome extension to ECS by helping students develop a repertoire of computational practices that expand into electronics and crafting. However, integrating such a complex array of skills and concepts requires extensive teaching practices that have not been clearly articulated for either computing or maker activities. Research on teaching for understanding across all subject-area classrooms [13] has shown the value of particular teaching practices in the classroom, including: ambitious and meaningful tasks that reflect how knowledge is used in the field, active learning, drawing connections to students' prior knowledge and experiences, scaffolding the learning process step-by-step, assessing student learning continuously, providing clear standards and feedback, and encouraging strategic and metacognitive thinking.

In putting e-textile making into computer science classrooms, these teaching practices take on disciplinary characteristics. A study of teaching practices across nine ECS classrooms revealed that teachers support an inquiry-based approach for student learning through particular practices: focus on the problem solving process rather than emphasizing the "right" answer, pose initial prompts and questions that facilitate thinking and exploration, engage students with hands-on activities so they can apply and test what they know, encourage creativity and risk-taking, promote collaboration, connect to students' prior knowledge, and employ journal writing as a tool for reflection [23]. These are practices that ECS teachers have already been trained in during two years of professional development. Yet teaching practices needed for transforming a computer science classroom into a makerspace has thus far been unexplored in the research.

Beyond integrating successful ECS practices into the e-textiles curriculum (e.g., journal writing, collaboration, prompts that support exploration), the curriculum needed the additional layer of transforming a computer science classroom space into a physical and intellectual maker space that promoted the sharing of expertise and valued personal expression—two key features of maker activities. For this we turned to constructionist pedagogy [26], promoting student designs of shareable artifacts. One often overlooked area of constructionist pedagogy is the social fabric that supports such creating. As students pursue projects based on personal interests, a single teacher or leader would be hard pressed to help every single student with all the challenges that arise in making their projects. Peer pedagogy [11], or peers helping each other, is one social aspect of constructionism that has proven to help in this regard. Yet more needs to be understood about how teachers can validate students' knowledge and expertise in ways that promote peer pedagogy. This dimension of supportive peer interactions become particularly critical when working with hybrid artifacts such as electronic textiles that require coordination across multiple modalities and sharing of expertise in different domains such as crafting, engineering and computing [20]. Not only different domains of knowledge but different value systems and means of creating (i.e., top-down, bottom-up; see [33]) need to be respected in order to create a more inclusive environment where students can bring in funds of knowledge [15] to pursue interest-driven projects. In addition, there must be a shift from a model that promotes equal access to resources and artifacts to one that focuses on more equitable allocations, realizing that the pacing of projects might vary based on prior knowledge and interests, while still helping students to achieve some core knowledge and skills that are important for further work.

Drawing on the ECS curriculum, constructionist pedagogy, and e-textiles projects laid the groundwork for integrating making into ECS computing curriculum. However, teaching the unit meant putting these ideas into action in actual classrooms with larger number of students than often present in makerspaces. A particular challenge teachers faced in introducing making e-textiles into a computing classrooms was how to value student interests and personalization while supporting equitable depth of learning, especially in the face of limitations of school-based class periods and staffing. In many makerspaces there are several mentors available whereas classroom have only one teacher. 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 what practices teachers developed that supported students' e-textiles making that was personal, interest-driven, and rigorous?

3 CONTEXT

The ECS initiative comprises a one-year introductory computer science curriculum with a two-year professional development sequence [22]. The curriculum consists of six units that address topics like human-computer interaction, problem-solving, web design, programming with scratch, computing and data analysis, and robotics with Lego Mindstorms. Each of the units addresses big ideas and includes recommended lesson plans but leaves room for teachers to expand. ECS has successfully increased *diversity* of participation in classes to representative rates in Los Angeles and has subsequently scaled nationwide to other large urban districts and regions, now with over 2000 teachers nationwide [17].

The ECS e-textiles unit was co-developed with ECS experts to be taught as one of the final units, replacing either the data or robotics unit [14]. In developing six e-textile maker activities, we combined aspects of making such as crafting, design and personal expression with challenging concepts in computing and electronics. Students were introduced not only to conductive sewing and sensor design, creating simple, parallel, and computational circuits [21] but also to programming sequences, loops, conditionals, and using Boolean logic to handle data from various inputs such as switches and sensors. The final e-textile project incorporates a handmade human sensor created from two aluminum foil conductive patches that when squeezed generate a range of data (see Fig 1). Students used this data to program different lighting effects so that the lights changed based on how hard a user squeezed their e-textile designs. Here we saw students make a wide range of personal artifacts such as stuffed animals, paper cranes, and wearable shirts or hoodies, all augmented with the sensors and actuators.

3.1 Participants

In Spring 2016 two experienced ECS teachers from the same large urban school district in California volunteered to be the first to pilot the e-textile unit in their classrooms. They had more than 8 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 staff as teacher-leaders who understood the issues of inquiry, equity, and computing that are the focus of ECS training. The teachers engaged in three days of professional development (once a month for three months) where they designed and created the six e-textiles projects students would later make to become familiar with the curriculum.

Angela (all names of people and places are pseudonyms) taught at a small, alternative, school-wide medical and science magnet school situated in an unincorporated neighborhood of the metropolis and part of the very large public school district. 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. 89% of Douglass/Williams' students are from socioeconomically disadvantaged families, 3% are English learners, and 53% are academically on-track or deemed college/career ready. Although all of the students had applied for admission to the school and its desirable magnet programs, Angela told us that none of the students in the elective ECS class had been selected for the school's 11th grade hospital internship program because they lacked the requisite course credits. Angela's pilot ECS class included high school juniors and seniors, 11 girls and 13 boys (21 of 24 students gave consent/assent for research).

Ben taught at a large, independent charter high school located in the suburbs of the metropolitan city. Valencia Glen Charter High School enrolls about 4,600 students, with 4% African American, 18% Asian, 10% Filipino, 40% Hispanic or Latino, 25% White, 1% two or more races, and 2% race not reported [10]. Fifty-four percent 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 all 9th grade students at his school. The class included 13 girls and 22 boys (32 of 35 students gave consent/assent for research). We were not allowed to collect demographic data on the students participating in the class and can only report information on a school-level.

4 METHODS

During the implementation, two researchers visited each classroom about four days a week for the duration of the e-textiles unit (8-10 weeks, with testing, student assemblies, and other school requirements interrupting the unit). We documented teaching with detailed field notes and pictures of student work supplemented by three interviews with the teachers (before, during and after the unit), video recordings, and daily recorded reflections by the teachers after each class. We also conducted brief interviews at the end of the unit with all consenting students.

We conducted the analysis in multiple stages with different levels of coding based on grounded theory and using constant comparative analysis [31]. In this analysis we focused on teaching practices that emerged in the context of making in the classroom with an eye towards equity. The research team met weekly to compare, review, and refine coding schemes together, writing memos to refine analysis before applying codes a second time across the span of the data. Discussions focused on what teaching practices emerged because of the challenges and opportunities in making in the classroom. We compared our findings from observational data with the interviews from teachers and students, finding areas of convergence. We also looked at the breadth of field notes in the data to see if themes remained consistent. In this paper, we focus on two overarching categories of teaching practices that illustrate how teachers implemented e-textile maker activities in their ECS classrooms.

5 FINDINGS

It is worth noting that both teachers implemented the e-textile activities in classrooms with a higher ratio of students to adults than observed in typical makerspaces: Angela's class had 24 students while Ben's class even had 35 students (no assistants helped the teachers). How then did teachers engage students in making e-textiles in their large classes? Amidst the challenges of managing the hourly transformation of a regular classroom into a temporary e-textiles makerspace, two emergent teaching practices stood out: (1) legitimizing student expertise and (2) supporting personal connections in e-textiles projects. In the following sections, we provide more detail on how these teaching practices supported key features of maker activities in a computer science classroom setting.

5.1 Legitimizing Student Expertise

One key feature of makerspaces—the availability and sharing of expertise that help participants complete their projects—is difficult to replicate in school classrooms where often the teacher is seen as the resident expert. In the ECS classrooms, teachers developed various strategies that involved valuing students' expertise and making it visible to other students. By doing so teachers forefronted student knowledge, validated students' efforts (including their mistakes and fixes), and supported students in going deeper into their projects. They did so in several practical ways.

One way that they legitimized student expertise was to feature students' projects during whole class teaching moments. For instance, Angela used two students' paper circuit cards (Project #1) to her class as a way to introduce how to create parallel circuits. She showed photographs of their cards (visibly laid out with 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.

Ben provided another example when he asked students to create computational circuits (circuits that light up in connection with a computer rather than directly linked to a battery): he had students first draw diagrams individually and then invited them to come up to the board to share with others what they had drawn. Such teaching moves not only encouraged a type of discovery-based learning, where students had to make informed guesses about how to create a computational circuit diagram, but also allowed for the display and discussion of multiple solutions to a circuitry design problem. Making students' work visible to each other in this way is a form of "open tool" [18] that allows everyone in on the thinking processes behind key skills and knowledge, such as planning circuitry, debugging code, or learning a crafting technique.

The teachers further legitimized student expertise by supporting peer pedagogy [11] with students teaching students. This happened in multiple ways and was often teacher-facilitated. Sometimes a teacher would explicitly invite a student to help another student. One way Angela did this was by requiring that student pairs approve each other's circuit diagrams before they moved on to crafting. Other times students would still turn to her as the teacher for approval, but she would redirect them to their neighbor and ask 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. 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 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 Fig. 1).

Figure 1: Tonio tutors Moisés in how to iron aluminum foil patches onto his project. ©Deborah Fields

Other forms of peer pedagogy happened on the students' own initiatives, supported by the physical structure of the classes with clusters of 4-6 students sitting around common tables. While working with a partner on the banner project explicitly facilitated collaboration, peer pedagogy was ubiquitous throughout the units. Debugging each other's work was extremely common, as noted in our observations as well as in the students' interviews. Parushi (from Ben's class) described one such instance during the banner project (#5) with her partner Emma:

> "I'd sewn the light incorrectly when (my partner) 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 expressed, "[I learned] the programming, 'cuz I see how he do it. Sometimes I'll... forget, and 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). The visibility or "seeing" of each other's work enabled students to catch mistakes and learn techniques they would not have on their own. These strategies of having students help each other also relieved some of the pressure from the teachers to be the sole source of expertise in the classroom, freeing them up to help with the more difficult problems that arose.

5.2 Supporting Personalization

Another set of practices emerged around creating an environment that facilitated students' displaying and connecting to their personal interests in making their e-textile projects in the class. One simple way that this happened was by the project designs that allowed creativity within constraints, enabling students to display personal interests in their projects. In each project there was ample room for personal expression: paper circuits became birthday cards for friends, wristbands displayed initials and popular media motifs, and LilyTiny (programmed microcontroller) projects became monsters, hearts, and cartoon characters.

In the context of the collaborative 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 in 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 intentionally worked to make theirs different, choosing to make the S like a snake in a southwest desert theme (see Fig. 2). They expressed their pride in their design during the exit interview:

> Interviewer: 'What are you most proud of?'
> Clarence: "The snake that we made."
> Everett: "Oh yeah... it was just better than the other [S]."
> Clarence "...It's different from all the other ones."
> Everett: "And better than the other [S]."
> Clarence: "We added layering, and also the LilyPad was inside."
> Everett: "Oh yeah, the LilyPad didn't show, the wires didn't show, just the LEDs."

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 2: Clarence and Everett's southwestern style "S" ©Deborah Fields

The teachers also supported this personalization by forefronting 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 told her 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 much more invested in their projects and even learn more through the design changes made in order to achieve the desired effects [20]. 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 took these ideas to heart and made sure to allow time at the beginning of class as well as 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 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 also made connections with skills that 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. Diego (Ben'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. 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.

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.

> **Kadir**: 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. So I came back.
> **Interviewer**: Can you give me an example of one of the changes that you made based on some family input?
> **Kadir**: So... the greeting card with the copper tape. I took that home, it was pretty dreadful, looked horrible. My mom's like: Why don't you make it a birthday card, put some stickers on it and stuff? I was like: Okay. I just designed it, put it on, it looked so much better. (160525, interview).

Most students remembered Kadir's greeting card because there was a tremendous difference between how it looked when he took it home one day when compared to the next day after he brought it back.

The ability to take projects home should not be taken for granted. At the beginning of the e-textile ECS unit the teachers expressed some concerns about allowing students to take projects home. 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. However, letting students take unfinished projects home meant supporting connections between home and school. It also taught students about the value of materials and trusted them to return with them intact and on time. This trust formed the basis for practices of training students to treat materials with respect and to be responsible for them in and out of class.

The focus on personalization also facilitated one other important aspect in both classes: peer friendships. This relates less to direct personalization of projects and more to personalization of the classroom by the indirect encouragement of friendships in that space. 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 and personalizing their projects. This is in addition (but related) to the peer pedagogy that we observed when peers were helping 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. 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 help in times of need as with Harold. 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, the type of classroom management that teachers supported, and the validation of student expertise (discussed in the prior section) seemed to allow peer friendships to grow and made the entire class more personal feeling to students.

6 DISCUSSION

Our paper took a first stab at articulating what some have called a 'pedagogy of making' [29] applied to a discipline-based classroom. Our analyses illustrated how teachers can integrate maker activities into computer science high school classrooms. We learned about some of the strategies that teachers successfully employed in implementing a newly developed unit on e-textiles and witnessed students' active and continued engagement as they designed, sewed, coded, and debugged their projects.

The first year of curriculum implementation was a success in broadening and deepening access to making: teachers reported that nearly all students were engaged, and it succeeded at diverse large classrooms. Simply by completing (or mostly completing) the projects, students attained some level of rigorous learning of programming, circuitry design, and problem solving. The bigger question in this paper is how the teachers themselves made this possible in the classroom given that the context was so different from most makerspaces: one leading adult instead of many adult mentors, a space that required mobile supplies in order to shift from making to other classroom work within the hour rather than a dedicated makerspace, and time limited to traditional class periods rather than extended periods of time. While the 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.

Our teachers illustrated how they broadened access and deepened participation in making: by facilitating peer pedagogy and legitimizing students' knowledge. The design of the classroom space and time allowed students to visit with each other in ways that promoted cross-fertilization of ideas and the development of personal friendships. In their classroom management the teachers also implicitly encouraged students to move about the room, talk with each other, and share ideas. Not only did those practices value student expertise and promote community, they provided a means for a single teacher to support 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.

We want to be careful to note that not all of these positive practices happened in every class, and not all students were happily on task all of the time. Nor in the space of this paper can we detail all of the things that the teachers did that supported making in personalized ways in the classroom. Yet we hope that by naming these aspects of teaching and the values underlying them we can help other teachers identify practices and elements of classroom design that reinforce personalized, rigorous making in discipline-based classrooms that support greater equity in reaching out to more students.

Further research needs to be done on the potential difficulties faced by the interdisciplinary nature of electronic textiles and similar making activities that draw on computer science. While the e-textile activities in our curriculum could be integrated within other disciplinary contexts such as science education [32], the coding required in the final projects would pose challenges for inexperienced or new teachers to help debug students' projects. This is a larger issue that maker activities will have to address as they often combine multiple disciplinary contexts but face K-12 education that has clearly delineated curricular boundaries. It also poses challenges to teachers who might feel more at home in one area and are not prepared to deal with all the issues that come up when there are overlapping areas of necessary expertise (i.e., making and computing, or circuitry and crafting). But shifting making into a different context such as computer science disciplinary 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. In this process pertinent practices of making, learning, and teaching will emerge, calling for more research and documentation to ensure that these practices can be named, refined, and shared. In doing so we can help discover 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 [2].

ACKNOWLEDGMENTS

This work was supported by the National Science Foundation (#1509245) to Yasmin B. Kafai, Jane Margolis and Joanna Goode. The views expressed are those of the authors and do not necessarily represent the views of the National Science Foundation, Utah State University, the University of Pennsylvania, the University of California, Los Angeles, or the University of Oregon. Special thanks to Jane Margolis, Debora Lui, and Justice Walker for earlier readings of this paper, to John Landa for co-writing the curriculum, and to our two pilot teachers and their schools for supporting the first implementation of our e-textiles unit.

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