Collaborative Electronic Textile Designs by High School Youth: Challenges and Opportunities in Connecting Crafts, Circuits, and Code

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ABSTRACT
Most electronic textile (e-textile) activities for beginners focus on making and coding individual projects leaving aside the potentially beneficial interactions that can occur as part of collaborative designs. In this paper, we report on an e-textile workshop with high school youth (ages 14-16 years) who were designing in groups interactive table centerpieces using LilyPad Arduino, LEDs, and conductive thread and fabric. We examined groups' approaches and reflections to two different collaborative structures, assigned roles versus assigned parts, and their interactions around project idea generation and circuit design documentation. In debriefing interviews, students reflected on other critical factors that supported or hindered their collaboration. Finally, we discuss the challenges and opportunities such collaborative designs can offer for broadening participation in coding and making.

Categories and Subject Descriptors
K.3.2 [**Computers and Education**]: Computer and Information Science Education – *Computer science education*; K.8.0 [**Computers and Education**]: General – Tangibles.

General Terms
Human Factors

Keywords
Electronic Textiles, Novice Programmers, Collaboration, LilyPad Arduino

1. INTRODUCTION
Many educational efforts are underway to broaden access to and participation in maker and coding activities to address the underrepresentation of women and minorities. Some efforts have examined the social and cultural barriers that impede participation [e.g., 11, 21, 22] or focused on developing new activities like game [15] and story design [25] to recruit more girls and women into computing. Other efforts have focused on developing programming tools to simplify the mechanics of learning to program and helping novice programmers to become more fluent and expressive with new technologies [e.g., 20]. Tangible construction kits such as the Lilypad Arduino [6] are a new development and include sewable microcontroller, sensors and actuators, to teach programming and engineering concepts. While electronic textile (e-textile) construction kits are similar in many functional aspects to robotics construction kits, these kits use soft materials rather than motors and gears, and they incorporate crafting techniques such as sewing that historically have a more feminine orientation.

Electronic textiles are part of a growing group of maker activities that can reveal how digital media is made *and* designed, combining the physical and digital [8]. Several studies have now documented how students can learn computational concepts, engage in computational practices, and broaden their computational perspectives with e-textiles [e.g., 17, 19]. For the most part however, the fabrication of e-textile designs have involved individual productions that give each student access to learning crafting, circuitry and coding. Exceptions are collective e-textile projects where students have designed quilts composed of several individual but not connected pieces [18] or the piano keyboard where designers craft and program individual keys that can be connected into a room-size playable keyboard [9]. The space of collaborative e-textile designs has been surprisingly underdeveloped even though computer science education considers collaborative approaches such as pair programming [32] a particularly rich and supportive context for beginning programmers.

In this paper, we report on the design and implementation of a collaborative e-textile workshop that we conducted with 19 high school students (14-15 years) as part of their science class. Drawing inspiration from collaborative robotics activities that are part of many introductory computer science curricula such as *Exploring Computer Science* [12], we examined possible collaborative designs with e-textiles and how learning of crafts, circuitry and coding would be situated in such a collaborative design activity. We analyzed students' completed artifacts, collaborative design approaches (and how they evolved over time), and reflective interviews guided by the following research questions: (1) How were students' collaborative interactions situated in their e-textile designs? (2) What did students have to say about their collaborations and learning? In the discussion, we highlight what we can learn from our experiences about developing and improving collaborative designs with e-textiles.

2. BACKGROUND

Collaborative learning is popular in education and hundreds, if not thousands, of research studies have investigated various aspects of collaboration, including the nature of various group arrangements such as reciprocal teaching or jigsaw techniques, interactions with members of different gender, race, ability, and experience, and causes for success and failures of group work [24, 31]. Likewise, in computer science education, comparative studies showed that pairs of middle school girls outperformed students working on their own in learning programming concepts when designing games with Alice. Both designing and playing a video game alongside peer proved to be a crucial way that children understood the nature and function of code [33, 34]. Other work has focused on collaboration and computing in the online space such as the Scratch community documenting how teams of young designers can successfully collaborate on programming and sharing media designs [16].

Moving from programming screen designs to hybrid crafting designs brings a whole host of challenges and opportunities for learning programming [4]. Most prominent are studies that have examined learning with robotics [for overview, see 1, 3]. Other research has focused on the creative explorations that are possible because of collaborative interactions [27, 28, 29] or examined the nature of peer interactions [14]. While robotic activities have introduced large groups of students into computing and engineering, they have also found to be a fairly exclusive domain with at most thirty percent of participants to be girls [13, 23, 30]. E-textiles' materials and activities have been found successful as alternative points of entry for underrepresented groups, in particular women [7]. E-textiles use "soft" textile materials that are sewn and embroidered with conductive thread and then programmed. Most e-textiles are meant to be wearable artifacts that are made for individual consumption unlike robotic artifacts that for the most part are designed to participate in public competitions. With collaborative robotic designs as an inspiration, one goal of this study was to explore the space of collaborative e-textile designs, the nature of possible artifacts, the interactions between team members, and final performances other than competitions.

Another consideration was how collaboration could be distributed in e-textile designs that requires coordination across different domains such as crafting, circuitry and coding—none of which most students are familiar with. Establishing successful collaborations in small teams has been a primary focus of much educational research given how often such collaborations fail [2]. Many approaches assign particular roles such as note taker, designer, or programmer to group members that are connected to the functionality of the artifact to be designed [5]. Research has also shown that in collaborative programming projects, girls often get relegated to the planning and non-technical activities leaving the access to computer and programming activities to boys, further amplifying gender inequities so prominent in hi-tech activities [10]. In the context of hybrid designs such as with robots and e-textiles, participation is further limited in access because of space, but also because of the interconnections between activities such as circuit design, sewing, and coding. For that reason, we investigated not only the assignment of different roles to team members but also the assignment of different programmable ports as a way to structure collaboration between team members in crafting a collaborative e-textile artifact. While the former is a fairly common structure in collaboration, the latter presents a new take on how to structure collaboration between team members. The goal of this study was to examine artifacts, interactions, and reflections of participating students to understand opportunities and challenges in making and learning with collaborative e-textiles.

3. CONTEXT

3.1 Site and Participants

We conducted this study with 19 high school sophomores (16 girls, 3 boys, 14-15 years old) at a charter school in a metropolitan city in a US northeastern state. The class represented the demographics of the school: 44% Black, 35% White, 13% Hispanic, and 3% Asian and 3% Multi. All participating students were self-selected "STEM Majors" (20% of students at the school were STEM Majors) who had been together to for nearly two full school years, so they were generally well-acquainted with one another. Students self organized into five groups, with three to four members. In addition to the teacher, a trained biologist, two researchers, the first and third author, and a graduate assistant who also was a designer, worked closely with the teacher to introduce the activities, and support the design, crafting, and coding of the collaborative e-textile projects.

3.2 Design of e-Textiles Workshop

The collaborative e-textile workshop was introduced as the final unit of the science class. Prior to the workshop, students were primarily conducting formal lab experiments situated in chemistry and biology; earlier in the school year, though they had a brief introduction to engineering and robotics. The e-textile workshop met daily for a block of 105 minutes over nine days: the first four days we introduced different components of e-textiles such as making a simple circuit using conductive thread, needle, LEDs, and a battery. To situate this starter activity, each student designed and crafted their own bracelet made of felt using the snaps to close the circuit (see Figure 1).

Figure 1: Examples of e-Textile Bracelet with snaps and LED (left) and the back of bracelet with battery holder (right).

The last five days of the workshop were dedicated to the design and completion of the collaborative e-textiles. In consultation with the teacher, we decided to focus on interactive table centerpieces for the school-wide end-of-year STEM Majors exhibition. During the "Food Fight," freshman STEM majors in the school are divided into two teams and prepare meals alongside professional chefs using the tilapia and vegetables they have raised and grown all year as part of their science class. To provide students with a model and ideas of what a table centerpiece e-textile could look like, we built our own prototype as an example (see Figure 2).

We shared the circuit designs and prototype with the student groups as part of the introduction to the project. Additionally, each group received the code for our prototype to remix and use for their own projects. The prototype project was more complex—8 LED lights and two sets of sensors—than what students were expected to achieve for their projects. We guided students through a design process of brainstorming, translating their ideas into circuit design documents, and finally crafting their projects. Additionally, the teacher worked with an undergraduate assistant to create a much larger interactive table piece for the punch table at the event, crafting and learning alongside the rest of the class.

Figure 2: Prototype of Collaborative e-Textile Centerpiece (top) and backside with stitched circuit design and LilyPad Arduino (bottom).

3.3 Data Collection and Analysis

We collected a range of qualitative data focusing on what groups were doing and how students were interacting with each other as they were collaboratively creating, crafting, and coding their e-textile design. In addition to photo documenting the progress of students' artifacts throughout the project, we also used video to record three of the five groups over the course of the nine sessions. At the conclusion of the workshop and exhibition, we conducted open-ended group interviews with members four of the five groups (a total of 12 out of 19 participants) in which we asked about the design process for their collaborative project and their impressions of their groups' interactions and collaborations. Each interview lasted between 15-20 minutes and was then transcribed by the third author.

Our analyses for this paper focused on interview data and consisted of several rounds of qualitative analysis driven by two key themes: processes of collaborating and designing. With these in mind, we (the first and third authors) completed line-by-line analysis using a combination of descriptive and in vivo methods and worked together to theme the data [26]. Both researchers analyzed all of the interviews, discussed discrepancies, and developed new codes as needed. We report the findings of this analysis here, and draw from other data sources to qualify and expand our interpretations.

4. FINDINGS

We begin with an overview of the collaborative e-textile centerpieces designed by each group before report findings from the interviews. The e-textile design were displayed at the Food Fight event attended by close to one hundred students, teachers, and parents who came to sample the food and select a winner.

4.1 Collaborative e-Textile Designs

We asked each student group to design and craft an interactive table centerpiece for their end-of-the-year STEM exhibition, called the "Food Fight" in reference to popular TV shows. All groups, except one, drew inspiration from this event and picked an ocean theme for their project.

Figure 3: **Fish (top) and Ocean (bottom).**

The **Fish** group consisted of two boys and two girls who developed an interactive fish centerpiece (see Figure 3, top). They sewed four LEDs onto the fish, mounted one set of sensors onto the fins, and added other decorative sea creatures to their piece. The group sewed the fish to their felt base and stuffed it with felt pieces for a more 3D feel. The final code they uploaded to their project synchronously blinked all of the lights once then alternated turning each light on and off one more time. The **Ocean** group**,** another mixed group with one boy and three girls, crafted an interactive ocean scene (see Figure 3, bottom). They sewed five LEDs and one set of fish-shaped sensors onto the base, and added various sea creatures cut from felt. The centerpiece included 3D elements such as a small stuffed rock. The final code the Ocean group uploaded to their project cycled through the LEDs, blinking each LED individually before moving on to the next.

The all-girl groups included **Dolphin** with three girls who built an interactive dolphin table centerpiece (see Figure 4, top). They sewed eight LEDs with two eyes on each of four dolphins and a set of sensors onto the project, along with 3-dimensional dolphins, stuffed fish, and a 3D tree. The dolphins consisted of two felt pieces mounted on each side of small pieces of cardboard to help them stand perpendicular to the base of the project. The team did not complete their code by the end of the project, but they managed to get two dolphin eyes (LEDs) to blink. The **Octopus** group also consisted of four girls who designed an interactive octopus centerpiece (see Figure 4, bottom). They sewed four LEDs and a set of sensors onto the tentacles of a 3-dimensional octopus; therefore the light sequence could be activated by touching both sensors at once, or by touching the two tentacles with sensors together. The octopus was designed around a styrofoam ball and decorated with a face, bib, and sequins. The final code synchronously blinked all the LEDs at once, then turned all the LEDs on in turn and off in turn, with one of the four LEDs coming on a third time during the sequence.

Finally the **Flower** group of four girls created a flower centerpiece not inspired by the fish them but by their starter project bracelet designs (see Figure 5). They sewed five LEDs onto felt flowers on the base of the project, and positioned a set of sensors on top of two felt lilypad shapes at opposite sides of the base. The final code turned each LED light on and off in turn, cycling through all the lights multiple times with a varying order.

4.2 Collaborative Structures and Interactions

Though all groups consisted of self-selected members and designed the same table centerpiece artifact, the way in which group members interacted differed based on their collaborative structured. We assigned two collaborative structures: roles or pins. Four of the five groups assigned roles within their groups using cards with descriptions such as aesthetic designer (the person who would lead crafting), circuit design (the person who would lead circuitry), and program designer (the person who would lead coding). Groups of four chose to have either two circuit designers or two program designers. One group assigned roles based on the pins of the Lilypad Arduino. Based on the teacher's recommendation, we selected the Ocean group to assign at least two Lilypad Arduino pins to each member, so that each person was required to design, sew, and program their assigned pins. In our analysis, we focus on how members negotiated their collaborations based on these different assignments. Our findings are limited to four groups since we were unable to interview any students from the Flower group due to the end of the school year.

Figure 4: Dolphin (top) and Octopus (bottom).

Figure 5: Flower.

4.2.1 Assigning roles

Within the three groups which self-assigned roles, there were two overarching approaches, or ethos, that seemed to affect their collaboration: individualistic and collectivistic. At least one group had an individualistic approach where they primarily worked according to their own role assignments. The other two groups took a more collectivistic approach where they fluidly transitioned between their individual role assignments and contributing to the collective goals of the project.

First, two members of the Fish group were absent on the day that groups assigned roles, which made this task particularly challenging for this group. The two members, James and Arianna, who were present chose the roles they wanted for themselves:

circuit designer and aesthetic designer, respectively. The next day when their teammates returned, they tried to renegotiate their roles. For instance, one member, Charles, recalled that when he returned, "I was confused because they picked jobs for us, but I didn't have no choice on what to do. They gave us coding so I just did it." In contrast, when Angela returned she protested to being both second programmer or circuit designer, and instead decided to become another aesthetic designer, which was not an option we originally offered. Arianna recalled, "I did aesthetic design, because I thought I was better for that… Angela didn't want to be the circuit, because she didn't know how to do that, so we did something [aesthetic designer] that she knew how to do." Interestingly, in addition to orchestrating the majority of the aesthetic elements, Angela still completed nearly all of the sewing for the circuit, but she did so without consulting James, the circuit designer, so she repeatedly had to re-sew several pieces of her circuit. According to our observations and confirmed in interview, the fish group worked rather individualistically throughout their project development.

The three members of the Dolphin group each took the role with which they felt most comfortable. Their role assignments were straightforward, yet as their project progressed, they identified a need to help their teammates to keep things moving forward. Chelsea, the aesthetic designer, explained, "So, I mean like the roles in the beginning worked out but then towards when you started actually making the project everybody just ends up helping each other." Melissa, the circuit designer, confirmed this process, "So I think it's like roles until you get yours done and then when you're done you just help whatever else needs to be done." The dolphin group took a collective approach to their project by which each person had a piece they were personally responsible for, yet each group member expressed a collective responsibility to get the project complete.

Finally, the Octopus group had a defined aesthetic designer, Zephanie, and programmer, Nina, but no one seemed to clearly own the circuit designer role. Nina explained, "it was hard because some people was [sic] absent, then people got sick and had to leave." Zephanie further elaborated, "we had to basically join together and find a solution. So we had to do our circuit over, what, like three times?" Together Zephanie and Nina shared the bulk of the work for their project, since their two teammates who shared the circuit designer role were either not present or did not have the sewing skills to complete their circuit design. Like the dolphin group, the octopus also took a more collective approach toward their roles, such that when they completed their own responsibilities they shifted to work on other aspects of their project. The Fish group used roles as boundaries for their participation whereas the Dolphin and Octopus groups interpreted the roles as guides for participation. In these cases, there was a stark contrast between using role assignments as individualistic boundaries versus collectivistic guides, in that, the Fish group struggled to bring everything together as a team. Based on these interactions, we suspect that fostering role-based assignments as a more collectivistic guide to participation might yield more fruitful interactions in collaborative designs.

We also encouraged students to work in a jigsaw fashion according to their roles, so that a circuit designer of one group would collaborate with another circuit designer from another group. While this did not come up in any of the interviews, we did observe program designers (but not aesthetic or circuit designers) working together across groups. Our data on these interactions are limited, however, it is another form of collaboration that emerged with the role assignment group structure.

4.2.2 Assigning Pins

As part of our investigation of collaborative design arrangements, we asked the Ocean group to self-assign pins rather than roles. By this, we expected that each member would take turns sewing the circuit and programming and the collective group would decide on aesthetic elements. After only about a day and a half this approach broke down and morphed into a more role-based approach. For instance, Nolan, the only boy member of the group, explained how he became the programmer, "at first we all said we were going to stitch our parts together, but then after that none of them knew how to code 'cause they weren't here that day [we learned coding], so I was like okay I'll do it." The other three members worked together to design and sew the aesthetic and circuit elements of the project.

In reflection, Samantha explained "at first we each had two pins and then eventually we changed it so that us three we did all the sewing and all the craft stuff, and Nolan did all the programming." Rachel elaborated on their interaction went, "[Nolan] listened to what we wanted to light up and stuff", describing how Nolan functioned in a consultant-type role to complete the programming for their project. Though this group moved away from the pin-based collaboration initially assigned, they adapted a more collective approach by taking turns sewing (except for Nolan) and communicating all aspects of their project with each other.

4.2.3 Negotiating Project Ideas and Circuit Designs

Regardless of their collaborative structure, groups discussed similar tradeoffs of working together on their e-textiles designs. Here we tease out two aspects of the process—the project idea generation and the circuit design documentation—that students across groups implicitly or explicitly identified as crucial to their progress.

While all except one of the collaborative projects were inspired by the STEM Food Fight event, developing a specific project idea became a point of tension for the groups. For instance, the Fish and the Dolphin groups both reported disagreements over their project ideas. With the Fish group, James expressed frustration that "we all had different ideas, but only used one," and Arianna was quick to agree elaborating on the root of her own frustration, "certain things I wanted to do they didn't want to do… all of us having different ideas." Likewise, the Dolphin group had a similar exchange:

> Chelsea: First we started off with the idea. I wanted to make a whale but then you two wanted to do dolphins.
> Melissa: I didn't care what we did. Don't say you two because Claire…
> Chelsea: You didn't want to go with my plan of a whale, and a whale would've been so much simpler… It was hard to agree on an idea…"

Both groups struggled to agree on a plan and direction for their project, however, the effect of this varied between the two groups. The Fish group repeatedly argued and had disagreements about the idea over the course of the project, whereas the Dolphin group was able to move past it. On the other hand, the Octopus and the Ocean groups were both able to agree quickly on a project idea.

Nina, a member of the Octopus group, explained that Zephanie was "the decider" and they all agreed with her octopus idea. With the Ocean group, both Nolan and Rachel explained "we just all agreed" in regard to their project idea and plan. Unlike individual e-textile designs, collaborative designs present a new tension for group members to agree on a direction and purpose for their project.

Moreover, groups highlighted the development of their circuit design documents as another crucial point in the design process. We saw across groups how the circuit design documents were used to translate and communicate their idea. These documents became a significant reference point to mitigate group interactions throughout the design process. Recognizing the importance of keeping the conductive thread lines from crossing, group members in three out of four interviews noted that they iterated their design documents throughout the process. For instance, Sasha explains how the Ocean group used the circuit design document: "we drew [the circuit design] like three times or four times and then we just made sure. Well, before we actually sewed it on we added tape as our outline and we labeled the tape with marker so we made sure we didn't mess it up" (see Figure 6).

Figure 6. The Ocean group's scotch tape circuit design.

The Ocean group realized the importance of the circuit design both in terms of getting their project to work and sharing the sewing responsibilities, so they translated their circuit design to their base felt with scotch tape. We, as facilitators, were inspired by this idea and plan to try it in future collaborative designs to explore whether it helps mitigate some of the tensions of idea translation and communication.

Groups who opted to integrate three-dimensional elements to their project reiterated the crucial significance of the design document in this process. For instance, the Dolphin group, who had the most complex circuit design, struggled to translate their idea onto paper and this inhibited their ability to communicate their ideas to us, so that we could support them. Melissa explained:

> "I think it was harder in the beginning because we wanted it to be 3D like it is now, and on the paper we can't make it 3D. Like when you guys were trying to help us it was just harder for you to see how we wanted it, because we knew how we wanted it, but it was harder for everyone else to see."

Despite this challenge, they persisted forward with their idea and completed about half of their project in time for the Food Fight exhibition. In contrast, the Octopus group recognized this challenge and instead altered their original idea to avoid sewing a 3D circuit altogether. Curiously, the Fish group, who reported the most disagreements and tension throughout their design process, did not reference iterating or using their circuit design documents. While we do not want to extrapolate too much meaning from this particular observation, it is clear that the circuit designs are the toughest, yet most important piece of the process, especially in collaborative projects.

4.3 Reflections on Collaborations

After completing the project, students shared more specific insights regarding challenges, task sharing, and timing of making collaborative e-textile projects and the group interactions around them. Reflecting on their collaborations, students elaborated on specific challenges with the crafting, circuitry, and coding facets of their projects. First, a common thread across students was negotiating an asynchronous design process simultaneously; in other words, that code cannot be tested on a given artifact until the circuit is completely sewed. For example, Chelsea, who worked in the Dolphin group, explains, "Claire is taking forever with the programming so we couldn't even test it to make sure it works, so then we had to wait for her, and it was annoying." For individual projects, this does not pose an issue, because there is always something to work on; however, in-group projects we observed and students reported periods where people were sitting around waiting for another teammate to complete their work.

Additionally, nearly all groups mentioned issues around task sharing, particularly with sewing. For instance, Arianna of the Fish group shares, "I thought it was gonna be confusing if two people were sewing two different things." She went on to explain that with two people sewing simultaneously they would probably cross lines and short circuit their project. As with individual projects, sewing the circuit takes the most time and is the most important element in terms of creating a project that works. We saw two strategies in this workshop that helped offset this confusion. First, the Ocean group took turns sewing and used scotch tape to be sure everyone sewed the correct lines. Second, the Dolphin group shared sewing responsibilities, because they needed to sew LEDs on different pieces (dolphins) separate from their base felt.

Moreover, all of the groups requested more time to work on their projects. On the one hand, with more time the Dolphin group collectively felt they could have better executed their complex 3D circuit. Likewise, Zephanie explains that the Octopus group abandoned their idea of sewing the circuit on "the styrofoam ball, [because] that would have taken more time." One the other hand, Samantha of the Ocean group elaborates how time impacted her limited participation of programming, "I think this is basically a problem with timing, because I think programming is really hard and it takes a while to understand, but because of the limited time we had we weren't really able to get used to it." Time is a realistic constraint of e-textiles projects, especially in formal settings, but it is important to consider the tradeoffs of how time might limit the scope of projects and participation.

5. DISCUSSION

The goal of this workshop was to investigate the potential of collaborative e-textile designs for high school students as an introductory activity into making, engineering, and computing. Unlike robotics activities that have a history of students collaborating in smaller or larger groups, e-textiles have been mostly individual designs. Such collaborative computing activities can provide a context for fertile group interactions and support, and they can also lower the cost of materials and electronics needed for students' design work in a classroom. In the following sections, we discuss what we learned about implementing and improving collaborative e-textile designs.

5.1 Opportunities and Challenges

We gained insights into at least three different types of social interactions that we observed within collaborative e-textile design. Task sharing over the course of a single project design became the most prominent form of collaboration that members negotiated within their groups. We also observed students working across groups according to their specific roles (i.e., programmers worked with other programmers). Finally, there was at least one clear instance of a consulting-like form of collaboration, where a programmer received feedback from his group members and wrote code accordingly. These observations suggest that e-textile designs can be supportive of within and between group interactions. Overall the collaborative e-textile designs provided opportunities to engage in the type of problem solving that Jordan and McDaniels [14] observed in small group robotics teams.

Major challenges in enacting collaborations were mostly due to not all students having the same experience throughout the project: some students learned how to code, others learned how to sew, and still others learned how to design complex circuits. Group members also agreed that designing and sewing the circuit was the most complex and challenge task, and that their circuit designs were critical in translating and communicating their plans. For instance, the Ocean group realized the significance of their circuit design and adopted a strategy of using scotch tape to more smoothly translate their paper circuit design to their fabric design. Their tape strategy also communicated their design plan to each other so they could more easily share sewing duties. Circuit designs are often used to translate ideas for individual projects, but in collaborative projects they also became a point of reference for all members to remain on the same page. To expand this strategy, future research should explore different methods of breaking down circuit designing and sewing into smaller tasks that can more easily be distributed across members or pairs.

5.2 Scaffolds for Collaborative Making

In light of our findings, providing scaffolds in form of group or design structures might facilitate collaborative e-textile designs. When exploring collaborations in complex problem spaces like e-textiles, we might consider the tradeoffs of depth and breadth in learning. In other words, when is it legitimate for a student to dive deep into a specific role or content area at the cost of other roles or content areas? We discuss two possible answers to this question. First, we previously identified three distinct practices—crafting, circuitry, and coding—in making e-textiles [17]. While we assigned these practices as roles to individual team members, we observed that groups with more than three members struggled to assign all members meaningful tasks. Though we had recommended that they share circuitry designer and program designer, theses roles did not turn out to be that clear-cut. For instance, the Fish group created two aesthetic designers. Even more telling, one member in the Octopus group claimed "I'll be anonymous" as her role, since she had not made a clear, meaningful contribution to the project. It could be that the roles must be broken down differently to resolve the tensions expressed by these two groups. But it could also be that these roles aren't as distinct as the practices are from which they derived. In fact, in analyzing students' making of e-textiles, we often noted the overlaps between different practices such as designing a functional circuit through which different LEDs can be controlled. Successful e-textile design hinges on understanding not just code or circuit designs but also how they intersect in their functionalities.

Another possibility is to constrain the collaborative space by simply having smaller groups. Inspired by the success of pair programming [34] we can think of "pair crafting" as an approach to collaborative e-textile designs. In traditional pair programming, students alternate between being the programmer who writes codes and the driver who directs and comments, placing novice programmers in different positions. This arrangement also mitigates the often contentious sharing of keyboard access. What would this look like in pair making? Here two students could alternate between multiple roles throughout a collaborative design process. The Dolphin group suggested defining the goals rather than of the project, so that they could collectively work toward those goals and contribute where needed. Perhaps, such an approach would better support pairs to alternate between physical and digital making.

6. CONCLUSION

Collaborative activities like the e-textile designs we explored in this workshop illustrate the opportunities and challenges in involving student teams in making and learning with two distinct modalities: the digital and the material. Certainly, e-textiles are only one of the many types of hybrid activities that combines the digital and material in authentic, aesthetic ways and can draw diverse groups of youth into identification with disciplines by connecting seemingly abstract computing and concrete, hands-on, do-it-yourself craft. Converting do-it-yourself into doing-it-together turned out to be a formidable challenge but also a productive opportunity that warrants further investigation.

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