Reflections on Pair E-Crafting: High School Students' Approaches to Collaboration in Electronic Textiles Projects

Breanne K. Litts, Utah State University, breanne.litts@usu.edu
Debora A. Lui, University of Pennsylvania, deblui@upenn.edu
Sari A Widman, University of Pennsylvania, sawidman@upenn.edu
Justice T. Walker, University of Pennsylvania, justicew@upenn.edu
Yasmin B. Kafai, University of Pennsylvania, kafai@upenn.edu

Abstract. Pair programming is one of the most popular and successful collaborative learning activities in computer science education wherein students organized in pairs alternate between writing and guiding coding on the screen. In this paper, we examine a complementary approach by taking pair programming into a tangible space where pairs coded lights and sensors of an Arduino-based microcontroller, designed programmable and functional circuits, and sewed an electronic textile. We analyzed the reflections of 23 students, who worked in pairs over a series of fifteen 90-minute workshop sessions, about their experiences collaborating and communicating across the different domains of e-textiles creation (e.g., design, circuitry, coding, and crafting). Student perceptions highlighted potential causes of these interactions across these multiple domains, which are distinct from pair programming activities. In the discussion, we address how these perceptions inform the design and development of more equitable pair e-crafting arrangements.

Introduction
The recent call for computer science education for all (Smith, 2016) stresses the need for better understanding the design of different contexts, tools, and communities for learning and teaching computing. One of the most promising arrangements in learning coding has been pair programming (McDowell, Werner, Bullock, & Fernald, 2003), wherein tasks and communication are prescribed within interactions between two individuals. While past research of pair programming has focused on screen collaborations, the potential benefits of these collaborations for more tangible computing activities (such as robotics or electronic textiles) is apparent, especially in terms of opportunities for peer support and reduction of material costs. For this reason, we focus on a new pair arrangement of work within these multimodal computational contexts that we call "pair e-crafting." Building on pair programming, pair e-crafting emphasizes partnership between students in building an electronic textile (e-textiles; Buechley, Peppler, Eisenberg, & Kafai, 2013), where students must negotiate the physical realm of electrical circuits sewn together with conductive thread, along with the digital realm of computer code that controls these circuits. In order to accommodate the multiplicity of these activities, individual tasks and interactions are not as prescribed as with pair programming; however, this partnership still requires coordination and team communication for success.

In this paper, we contribute an understanding of how students negotiate and coordinate the demands posed by multimodal computational work within a paired partnership. We draw on perceptual data to gain perspective on how student pairs conceptualized their engagement with each other, looking particularly at distribution of tasks and communication contexts. We interviewed a class of 23 students, who worked in pairs on e-textile designs, to address the following questions: 1) How did students conceptualize collaboration and distribution of tasks across the different domains of e-textiles creation? 2) How did they communicate within these collaborations? In emphasizing students' perception of these issues, our findings provide a basis on which to inform future implementation of collaborative, multimodal programming activities.

Background
Within the literature on novice programming, most studies have focused on student's individual performance in how they come to understand key programming concepts and practices (Soloway & Ehrlich, 1984). While some early studies found that students were not able to learn productively in small teams when compared to students engaged in solo programming (e.g., Webb, Ender & Lewis, 1986), other studies found that teams with experienced students design were more capable of providing equitable access to computer work for inexperienced members, calling this *peer pedagogy* (e.g., Ching & Kafai, 2008). The design of pair programming has addressed these benefits and challenges by more explicitly structuring the collaborative interactions between learners (McDowell et al., 2003; Denner, Werner, Ortiz & Campe, 2014). Equitable participation within collaborative teams becomes even more of an issue in multimodal computational activities

like e-textiles and robotics, where projects require coordination across screen-based and physical domains. From research on robotics, we know that collaborative interactions can be mitigated by uncertainty, gender, and agency (e.g. Sullivan, Keith, & Wilson, 2015). Similarly, studies on collaborative e-textiles arrangements suggest that equitable participation in the different required domains (design, crafting, circuitry, and coding) is difficult to accomplish depending on individuals' prior and perceived experience within these areas (Buchholz, Shively, Peppler & Wohlwend, 2014; Kafai, Searle, & Fields, 2014), something that can be exasperated within team collaboration of three or more (Litts, Kafai, & Dieckmeyer, 2015). In our current study of pair e-crafting, we explore smaller teams of two students emulating pair programming. From related work observing social interactions in pair e-crafting (Lui, Litts, Widman, Walker, & Kafai, 2016), we know that coordination of tasks and communication are key factors in determining pair productivity and success. For that reason, we primarily focus on students' perceptions of their pair experience, examining how students' understandings of tasks and communication framed their interactions, in order to help shed light on how to best address potential challenges and opportunities for collaborative learning.

Methods

Participants and workshop design

We conducted this study with 23 high school juniors (4 boys, 19 girls, 16-17 years old), within a STEM elective course at a charter school in a Northeastern metropolitan city. Prior to the study, the teacher put students in pairs aiming to balance personality traits and existing friendships. Over fifteen 90-minute class periods, pairs were guided through the creation of a collaborative e-textiles sign that spelled out the name of the school and was publicly displayed. Each pair was assigned a pre-designed canvas print of a single letter created by an art student in the same school, and responsible for making these pieces interactive by adding components such as LilyPad Arduinos, switches, sensors, and LEDs and generating codes four different light patterns. The teacher together with graduate assistants prepared and guided classroom sessions. After an introduction to e-textiles, the class was divided into two major phases. During phase one (roughly 5 days), pairs focused on project planning, including its *design*, when students made decisions about the aesthetics and functionality of their project, and its *circuitry*, when students mapped out the appropriate connections between the electrical components. During phase two (roughly 10 days), pairs focused on project construction, including *coding* the behaviors of the project using text-based Arduino code, and *crafting* by sewing the project together.

Data collection and analysis

At the end of the workshop, we conducted semi-structured interviews (averaging 15 minutes) with all 23 students individually, which we video recorded and transcribed. We asked about their processes working on their designs, experiences working with a partner, experience working on a design project, and their feedback on the structure of the course. Two authors coded all of the interviews in several iterative cycles following previously published coding methods (Saldaña, 2009). In the first cycle, we began with provisional codes, drawing from prior research on pair programming and e-textiles. We focused on two key features of pair programming collaboration (tasks and communication) and four domains of e-textiles (design, circuitry, coding, and crafting). We then employed several rounds to develop subcodes and themes. These are further elaborated in the findings. Across all interviews there were 215 coded excerpts in total.

Findings

In our findings, we provide students' perceptions about task distribution and communication, which shaped their peer interactions and design process.

Distributing tasks across e-textiles domains

Pairs described different approaches toward distributing tasks around domain-types. Of the 163 task-related excerpts (out of 215 total), 69 were coded as design, 39 as circuitry, 83 as coding, and 85 as crafting. The relative proportion of these domains corresponded to our observations of the class: students spent much more time with the coding and crafting of their projects than circuitry and design. These codes were not mutually exclusive, as our previous research on collaborative e-textiles revealed inherent interdisciplinarity of tasks (Litts et al., 2015; Lui et al., 2016). We also looked at whether, and how, students perceived the different e-textiles domains as supporting more shared or individual work approaches, something we coded as mutually exclusive. In terms of *shared* tasks, 80% and 79% (55 of 69 design codes, and 31 of 39 circuitry codes) of students' reporting on *design* and *circuitry* respectively, expressed these as shared rather than individual. As described by students, this resulted from the inherently interconnected nature of design and circuitry—that is, it is impossible to determine the visual layout of an e-textiles project without considering the necessary electrical connections, and vice versa. In terms of *individual* tasks, 54% and 59% (or 45 of 83 coding codes and 50 of 85 crafting codes) of students' reporting on coding and crafting respectively, identified work in these domains as individual rather than shared. Mostly, this was because crafting and coding were distinct tasks only one person could perform at a time and required different kinds of expertise. As a result, all pairs except one adopted more individual approaches towards these tasks. Thus, while students generally saw circuitry and design as more interrelated domains and thus more easily shared, they saw coding and crafting as domains that were inherently distinct, requiring separate realms of knowledge and skills.

Communicating within a pair e-crafting arrangement

Students reported three primary contexts in which they communicated about their project: decision-making, peer pedagogy, and absences. *Decision-making* (57 of 215 total excerpts) captures communication related to key project-related decisions pairs made throughout their design process. Most decision-making 54% (or 31 of 57) was related to the overall design of the project whereas 42% (25 of 57) were related to crafting, 40% (23 of 57) related to coding, and 23% (13 of 57) related to circuitry. This distribution can partially be explained by the prominence of design in the project in general. As described by students, project decisions involving design (i.e., the aesthetic placement of components, the usability of the project) always trickled down to the other domains of work. *Peer pedagogy* (33 of 215 total excerpts) captures instances where students reported teaching or learning from their partner, which most often occurred in the domain contexts of coding (21 times of 47 task occurrences) and crafting (20 times of 47 task occurrences) compared to circuitry (3 of 47 task occurrences) or design (3 of 47 task occurrences). Many students divided their labor within coding and crafting domains according to their relative comfort and expertise; however, when instructors asked students to switch roles, students described explaining their tasks to their partners as well as tips for how to be successful in these arenas. Students also reported peer pedagogy with regard to troubleshooting their project, because it required diagnosing whether the issue was due to circuitry, crafting, or code. Finally, a few students also mentioned *absences* (13 of 215 total excerpts) as a key context of communication. Dealing with absences presents a real-life challenge of doing heavy design work in teams over extended time periods. Almost all the pairs within the workshop dealt with at least one absence over the course of project, while a few experienced excessive partner absences (up to 8 over 15 days). Some of these students described overcoming this obstacle through explicit communication strategies, such as individual project updates outside of class or FaceTiming in class. One pair, though, did not explicitly address these issues and instead opted to work independently, which eventually led to feelings of frustration and difficulties completing the project on time.

Discussion

Our goal in this study was to better understand pair learning arrangements for high school students in making e-textiles designs in order to inform the design of future collaborative learning arrangements within computational contexts. In this section, we share what we learned from student reflections about equitable distribution of work.

Tensions of siloing work in pair e-crafting

Our findings reveal how collaboration can occur within the context of computational projects that involve both physical and digital construction. Though students had more potential avenues for individual engagement and interests (design, circuitry, coding, crafting), we also illustrated how this can work against more equitable learning arrangements through the creation of siloed work, roles, and identification. Given the multimodal complexities involved in e-textiles, it makes sense that students felt more at ease sticking with and developing a sense of expertise within a single domain. Here students emulated models of distributed labor that can be seen within many professional technological contexts, where teams are often comprised of different people with different expertise, knowledge, or skills. However, in educational contexts where we want students to gain equal access to different forms of knowledge and understanding, these distributed models of collaboration can result in ongoing knowledge inequities, wherein students who are already comfortable with certain topics (e.g., coding, circuitry) remain ahead and others remain behind. This inequity is further exasperated by the value judgments that are often affiliated with the different domains of e-textiles, which are usually viewed within the false binary of 'low-tech' or 'high-tech' (i.e., crafting and coding, respectively). Thus, in planning for pair work within multimodal contexts, it is important balance the benefits of supporting students' existing interests and experiences with the potential dangers of allowing students to self-segregate into these roles and identification.

Designing for fluency across domains

One major advantage of multimodal computational contexts for learning is that it can provide multiple avenues for individual engagement and learning (Kafai, Searle, & Fields, 2014). Within a classroom, however, there is a need to push people beyond their comfort zones toward new arenas. From this perspective, how can we promote the ethos of self-motivation and personal expression, even while getting students to do things that they might not otherwise pursue on their own? A possible solution is to leverage moments of decision-making and troubleshooting that naturally arise within these tangible computational contexts, as these interdisciplinary problem spaces require strategic sharing and negotiation of expertise between partners. Educators using pair e-crafting arrangements might consider capitalizing these moments by providing scaffolds to help students develop their inter-domain thinking and efforts. Another solution involves a more structured arrangement of sharing tasks that are more individual in nature. Borrowing from the pair-programming model (McDowell et al., 2003), this was something we implemented on the fly within the workshop when we asked students to switch roles. Not only was this a key trigger for peer pedagogy during which pairs taught each other their respective tasks, but also this process forced students to become more engaged with a new domain. In future designs, we plan to embed more purposeful task-switching throughout the design process to explore how it impacts equity in pair e-crafting. While this solution does not address all the challenges that student faced when working in collaborative maker arrangements, it is a foundation upon which more equitable work within making can occur.

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